CHAPTER 26 – Scaffolding Made Visible

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Introduction

The notion of *scaffolding* in instructional contexts is pervasive. According to the citation analysis tool *Publish or Perish* (Harzing, 2007), there are over 100,000 citations of scholarly works in this area. Despite the popularity of scaffolding, or perhaps because of it, there is substantial disagreement about what exactly scaffolding means: "the concept of scaffolding has become so broad in its meanings in the field of educational research and the learning sciences that it has become unclear in its significance" (Pea, 2004, p. 423). This state of affairs has led some to assert that, "there is no single right answer to what the word scaffolding means" (Sherin, Reiser & Edelson, 2004, p. 388).

This chapter presents a critical analysis of the concept of scaffolding as it has evolved over time. The analysis differs from existing reviews (Stone, 1998a; van de Pol, Volman & Beishuizen, 2010) in at least two ways. First, rather than assuming that scaffolding is a metaphor that needs to be formalized with a normative framework, we closely analyze source texts to uncover the epistemology of scaffolding. Second, rather than exclusively focusing on the origins of scaffolding, we use later work from the original line of research to augment and clarify its origins.

The analysis begins by examining the current controversies surrounding the common notion of scaffolding as a metaphor for support. After reviewing the history of scaffolding and its theoretical foundations, we explore the structure and function of scaffolding. We examine the implementation of scaffolding in human tutoring and intelligent tutoring systems. Our analysis suggests that key components of expertise have a larger role to play in scaffolding than appears in common practice. In particular, we argue that the most effective scaffolding makes expertise visible.

Scaffolding: Just A Metaphor?

In this section, we describe the status of scaffolding as a metaphor, the controversies surrounding the metaphor, and a shift in meaning of the metaphor in the field. A great deal has been written on the subject of scaffolding as a metaphor (Cazden, 1979; Greenfield, 1984; Brown & Palincsar, 1986; Palincsar, 1998; Stone, 1998a, 1998b; Pea, 2004; Quintana et al., 2004; Sherin et al., 2004; Lajoie, 2005; Puntambekar & Hubscher, 2005; van de Pol et al., 2010; Belland, Walker, Olsen & Leary, 2012). In a widely cited review, Stone (1998a, 1998b) examines what he calls the "metaphor" of scaffolding as discussed by Wood, Bruner, and Ross (1976). In the everyday sense, scaffolding is a temporary structure used by workers who are either building or repairing a building. However, using this everyday sense raises a number of questions when trying to understand Wood et al. (1976)'s notion:

> Discussions of problem solving or skill acquisition are usually premised on the assumption that the learner is alone and unassisted. If the social context is taken into account, it is usually treated as an instance of modelling and imitation. But the intervention of a tutor may involve much more than this. More often than not, it involves a kind of "scaffolding" process that enables a child or novice to solve a problem, carry out a task or achieve a goal which would be beyond his unassisted efforts. This scaffolding consists essentially of the adult "controlling" those elements of the task that are initially beyond the learner's capacity, thus permitting him to concentrate upon and complete only those elements that are within his range of compe-

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> tence. The task thus proceeds to a successful conclusion. We assume, however, that the process can potentially achieve much more for the learner than an assisted completion of the task. It may result, eventually, in development of task competence by the learner at a pace that would far outstrip his unassisted efforts. (Wood et al., 1976, p. 90)

It's quite clear from this description that instructional scaffolding is a kind of support. But Wood et al.'s description raises a number of questions if we consider scaffolding as a metaphor, because a metaphor invites us to interpret an analogy. For example, one can ask whether the tutor is the scaffolding itself, or if the scaffolding is supporting the tutor and the student as they work together on the building. The same issues of interpretation apply to the building the scaffolding surrounds. It is unclear whether the building is merely a solution to a particular problem, or whether the building represents competencies for solving an entire class of problems. The basic problem in interpreting scaffolding as a metaphor is that different interpretations implicitly make different theoretical commitments regarding the nature of learning and even the nature of cognition. In the example above, one might argue that the tutor can't be an active participant in the construction of student competence because such competence is internal to the student.

Without a theoretical framework to interpret it from, the metaphor of scaffolding is simply too diffuse to mean anything other than support. For this reason, many researchers explicitly connect the notion of scaffolding to Vygotsky's (1978) *ZPD*, although this connection wasn't explicitly made by Wood et al. (1976). The ZPD is a theory that reconciles the relationship between learning and development, namely, that learning precedes development. The ZPD "is the distance between the actual developmental level as determined by independent problem solving and the level of potential development as determined through problem solving under adult guidance or in collaboration with more capable peers," such that "what a child can do with assistance today she will be able to do by herself tomorrow" (Vygotsky, 1978, pp. 86-87). In other words, a child's development may be defined by two levels. The first level is defined by the child's independent problem solving – what they can do on their own. The second level, the ZPD, is defined by what the child can do with the assistance of others. Collaborative learning within the ZPD enables a child's development because it leads to future independent problem solving.

Ostensibly one would expect additional clarity to emerge if the metaphor of scaffolding were interpreted in the context of the ZPD. However, clarity remains elusive. For some, the ZPD can be incorporated quite simply, "Scaffolding can help learners accomplish tasks within their ZPD (Vygotsky, 1978) by providing the assistance learners need to accomplish tasks more complex than they could do alone in a way such that they can still learn from that experience" (Quintana et al., 2004, p. 340). Yet aside from introducing the ZPD into the definition, this version of scaffolding seems no clearer than before. In fact, it raises the further question of whether ZPD and scaffolding are simply two ways of expressing the same idea. For others, the ZPD has many implications that necessitate analyzing scaffolding in terms of essential features like contingency, fading, and a transfer of responsibility (Stone, 1998a; van de Pol et al., 2010). These features flow from the ZPD in the following way: the support from the tutor must be tuned to the student's ZPD (contingency), and because the student will inevitably learn, the tutor must reduce support appropriately (fading) so the student can assume a greater role over time (transfer of responsibility). In many ways, these deeper analyses convert the scaffolding metaphor into a theoretical concept, as is further discussed in the next section.

Puntambekar and Hubscher (2005) provides an insightful review of the evolution of the scaffolding metaphor from the original tutoring context of Wood et al. to the modern classroom context of teacher, peers, and artifacts like educational software. Using their own analysis of the essential features of scaffolding, Puntambekar and Hubscher conclude that much progress has been made in terms of providing support. Support can come from many sources (teacher, peers, or artifacts) and technological support is becoming increasingly sophisticated and diverse. However they also conclude that the emphasis on support has been at the expense of defining features of scaffolding like contingency and fading (see

Table 1). A tool that provides a fixed level of support to all students may provide too little support to some students and too much support to others. Any fixed level of support, by definition, is insensitive to a student's ZPD.

Table 1: Evolution of the Notion of Scaffolding. Reprinted with permission from Puntambekar and Hübscher (2005).

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

History and Analysis of Scaffolding

In this section, we review the origins of scaffolding and how it relates to the ZPD. Our central claim is that approaching scaffolding as a metaphor is ill-conceived. Instead we argue that scaffolding should be considered as a *label* for a theoretically well-defined phenomenon. The notion of scaffolding has been attributed to Wood et al. (1976) by a number of scholars (Brown & Palincsar, 1986; Wood & Wood, 1996b; Davis & Miyake, 2004; Pea, 2004; Lajoie, 2005), though some have been more cautious in their attribution (Stone, 1998a). Thus we review the depiction of Wood et al. (1976) and analyze it as being authoritative.

In the original description by Wood et al. (1976), scaffolding is not presented as simply a metaphor. Rather scaffolding is presented as a construct defined by a set of interrelated constructs. While the quote of Wood et al. in the previous section explicitly uses "a kind of scaffolding" to introduce the intuitive justification for the label "scaffolding" for a particular construct, this should be considered no differently than the use of "cancer" (from the Latin "crab," so used because of the crablike appearance of blood vessels around a tumor) to refer to that construct. Indeed, it is clearly foolish to speculate how crabs, by analogy, might help us better understand cancer.

In order to justify these claims, we briefly review the methods and findings of Wood et al. (1976). Their method involved a series of trials consisting of a child (ages 3–5 years), an adult tutor, and a task of assembling wooden blocks into a pyramid (the so-called "Tower of Nottingham" [Jones & Ritter, 1998]). The pyramid consisted of six layers. The top layer was a single block. The other five layers each consisted of four interlocking blocks, with each block in a layer of a different shape (A, B, C, D [Jones & Ritter, 1998]). The difference between layers was that each layer was successively smaller, yielding a pyramid shape. Once constructed, layers themselves locked together via a notch on the bottom and a corresponding knob on the top of the layer below. In other words, the problem consisted of creating layers (with each layer having the same type of solution structure) and combining the layers together. Because all blocks in the five layers had the same size interlocking knobs and holes and were the same thickness, it was possible to incorrectly assemble blocks belonging to different layers.

When a child entered the experiment room, the tutor, Ross, allowed them to play with a jumble of the disconnected blocks for 5 minutes. The tutor would then encourage the child the make a pair. From that point on, the tutor would intervene as little as possible in order to let the child perform the task themselves. The tutor would intervene in two kinds of situations. First, if the child could not or would not produce anything, the tutor would demonstrate or present a partial solution. Second, if the child attempted assembly but made an error, the tutor would either ask the child to compare their assembly to a correct assembly or directly correct the error.

In their analysis of the tutor's responses to the children's problem solving, Wood et al. noticed two shifts. The first shift was the relative amount of help needed by each age group. The 3- and 4-year-olds needed roughly the same total amount of help, but the 5-year-olds only needed half that amount. The second shift was the type of help required, either demonstrating (showing) or verbally intervening (telling). The 3-year-old ratio of show to tell was 3/2, but the 4- and 5-year-old ratio was about 1/2. So while the 3- and 5-year-olds were distinct both in the amount and type of help needed, the 4-year olds shared aspects of both: they needed as much help as 3-year-olds, but the type of help needed was comparable to 5-year-olds. This finding led Wood et al. to further elaborate on the intuitive label of scaffolding:

> It is in this sense that we may speak of a scaffolding function. Well executed scaffolding begins by luring the child into actions that produce recognizable-for-him solutions. Once that is achieved, the tutor can interpret discrepancies to the child. Finally, the tutor stands in a confirmatory role until the tutee is checked out to fly on his own. (Wood et al., 1976, p. 96)

If this were the end of their discussion of scaffolding, then it could be presumed that the term was meant largely in a metaphorical sense. However, Wood et al. proceed to not only indicate that their initial description of scaffolding was intended only as a teaser but also to outline an entire theory of scaffolding functions:

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

Wood et al. define six scaffolding functions based on their study. The first function is recruitment. During recruitment, the tutor draws the child into the task by gaining their attention, stimulating their interest, and fostering a level of commitment to the learning task. Through the second function, reducing degrees of freedom, the tutor reduces task difficulty to the appropriate level for the child's ability level. Direction maintenance, the third function provided by the tutor, keeps the child focused on the current goal and provides affective and motivational support when needed. Marking critical features is the fourth function, by which the tutor draws attention to relevant task features, such as highlighting incorrect solutions. The fifth function is frustration control. Frustration control by the tutor helps reduce negative affect that would impede successful learning. The sixth function, demonstration, consists of modeling the solution. Modeling can consist of a complete demonstration of the task, or a partial demonstration based on the child's current attempt.

It is worthwhile noting that scaffolding is presented as theoretical definition, or construct (Hurley, 2011). Quite clearly, it no longer refers to a metaphor for building, but has now been redefined in terms of a theory of optimizing learning during tutoring. It should further be noted that none of the scaffolding functions themselves are operationalizations. Rather, each function is its own construct. For example, there are many ways to recruit, many ways to mark critical features, and many ways even to model, depending on the task. Thus, although the study itself was limited to a problem-solving activity with wooden blocks, the scope of the scaffolding functions is much broader.

Given this fuller view of scaffolding, what then is the relationship between scaffolding and the ZPD? Again, this relationship is somewhat complicated by a lack of mention of the ZPD in Wood et al. It is quite difficult to understand precisely why the ZPD wasn't mentioned in Wood et al. when the work of the first two authors is considered. The second author, Bruner wrote the introduction to the 1962 edition of *Thought and Language* (Bruner, 1962), which mentions the ZPD by name (Vygotsky, 1962, p. 103), a decade before introducing scaffolding. In his introduction, Bruner also discusses Vygotsky's work using blocks problems in studies with children. Although these blocks problems typically used nonsense words to create categories for perceptually different blocks, at least one of Vygotsky's block problems has notable parallels: 22 blocks in four categories (Fodor, 1999). Finally, in later work, Bruner himself states that scaffolding was an attempt to better specify how the ZPD would work in practice (Bruner, 1986). The first author, Wood, in previously published work, writes of a "'region of sensitivity to instruction' – a hypothetical measure of the child's current task ability and his 'readiness' for different types of instruction" (Wood & Middleton, 1975, p. 181). The similarity of this description, "region of sensitivity to instruction" to the phrase "Zone of Proximal Development" is uncanny. Also in later work, Wood argues that the ZPD underspecifies both the nature of the guidance from the tutor and the learning that takes place in the student (Wood & Wood, 1996b). Thus, both Bruner and Wood's earlier work suggests that they were familiar with the concept of ZPD when they introduced scaffolding, and in their later work, they both portray scaffolding as an elaboration of the ZPD concept.

The assumption that the ZPD is a subtext to the original work of Wood et al., rather than connection made retrospectively, licenses fruitful interpretations and comparisons. In agreement with both Bruner (1986) and Wood and Wood (1996b), we argue that scaffolding is not identical or redundant to the ZPD, but instead offers some a more explanatory framework to an otherwise more descriptive theory. We characterize the elaboration of ZPD by scaffolding as having both theoretical and mechanistic dimensions. The strongest theoretical elaboration is the implied equation of comprehension and production with the endpoints of the ZPD:

> In the terminology of linguistics, comprehension of the solution must precede production. That is to say, the learner must be able to recognize a solution to a particular class of problems before he is himself able to produce the steps leading to it without assistance. (Wood et al., 1976, p. 90)

The theoretical contribution of this description is quite strong when interpreted in terms of the ZPD. According to the ZPD, what children can do independently is their actual developmental level, here equated with production. However, comprehension sets the ZPD itself, because it puts an upper bound on what the child would be able to do even with assistance. If the child is unable to comprehend a solution or partial solution to a problem, then that problem is outside their ZPD. To some extent this characterization is implicit in Vygotsky's discussion of language development and the ZPD (Vygotsky, 1978), but making it explicit leads to additional hypotheses and insights. Across the literature, comprehension and production are often asymmetric, and comprehension often seems to precede production (Clark & Hecht, 1983). However, task demands, such as asking children using gaze instead of pointing to respond to stimuli, can make this effect appear larger or smaller (Brandt-Kobele & Hohle, 2010). Clark and Hecht (1983) have argued that an essential part of learning language is the coordination of comprehension and production. They suggest that repairs to speech, whether repairs of pronunciation or wording, indicate that children are monitoring their own production. In their terminology, comprehension sets a standard for production. During production, both comprehension and production processes are active, and comprehension processes are used to monitor and repair production errors. This appears to be the characterization of the ZPD that Wood et al. intend: the ZPD is the gap between comprehension and production, such that the "knowledgeable other" provides monitoring and support in production to "coordinate" production and comprehension. Bruner calls this monitoring and support "vicarious consciousness" (Bruner, 1986, p. 74).

Scaffolding also elaborates the ZPD in terms of processes and mechanisms. Perhaps the most insightful is Wood et al.'s explanation of the tutor's behavior in terms of domain and student models. In the decades since, domain and student models have become regarded as defining features of ITSs that emulate human tutors (Woolf, 2008). They write:

> 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 the performance characteristics of his 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 mastery. 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 interaction between these models is implicitly the key driver for all the scaffolding functions they go on to define. This mechanistic explanation is an advance over Vygotsky, whose writings on the possible tutor actions were descriptive at best. Some examples of adult guidance or collaboration given by Vygotsky include asking leading questions, demonstrating, and solving problems in collaboration (Vygotsky, 1978). He does not outline when the adult should intervene or what kinds of guidance or collaboration are more appropriate in a given situation. Moreover, the examples given by Vygotsky, at best, correspond to only two of the six scaffolding functions of Wood et al., highlighting critical features (of which asking leading questions is an instance) and modeling (synonymous with demonstration). It appears the that processes and mechanisms of Wood et al. provide a fuller view of the phenomenon across its duration, ranging from recruitment at the beginning, scaffolding, and then the withdrawal of tutor support (also known as fading, see Collins, Brown, and Holum [1991]).

It is unfortunate that the domain of Wood et al.'s work, small children assembling blocks with a tutor, was so distinct from more formal educational domains. The gap between their domain and formal educational domains raises the further question of whether scaffolding, as they define it, is applicable to more practical educational domains. At first analysis, there seems to be reason to think that the theory of scaffolding is generally applicable. The ZPD was defined for classroom and non-classroom contexts, where the "knowledgeable other" could be either an adult or peers (Vygotsky, 1978). If scaffolding were assumed to be merely an elaboration of the ZPD, then it would stand to reason that scaffolding can be properly situated in these contexts. The problem, perhaps, is that scaffolding per se is defined with very fine-grained models of the student and the domain, and it is not clear whether a human teacher could simultaneously monitor the ZPDs of an entire classroom in order to closely adapt instruction (as noted by Puntambekar and Hubscher [2005] above). From this perspective, it may be the case that scaffolding does introduce a restriction on Vygotsky's original conception of the ZPD in that it requires more careful modeling than the ZPD originally warranted. After all, the activities that Vygotsky mentioned as guidance, such as demonstration, collaborative problem solving, and asking leading questions, don't necessarily require a fine-grained model of the student to implement.

A similar question may be asked for other tutoring domains: to what extent is Wood et al.'s conception of scaffolding applicable to tutoring in subjects like research methods or physics? In the blocks problem, everything is visible except the solution structure. The kinds of manipulations, like picking a block up, rotating it, or pushing it into another block, are essentially givens even for small children. In contrast, more formal educational domains have a good deal of invisible or abstract elements. Algebra, for example, requires knowing things, having familiarity with abstract operations, etc. Thus, the question as to whether Wood et al.'s notion of scaffolding is preserved between domains is a non-trivial one.

Several studies of naturalistic human tutoring have revealed the so-called "5-step tutoring frame" (Graesser, 1993; Graesser, Person & Magliano, 1995). These same structures have featured prominently in the work of other researchers conducting fine-grained analyses of tutoring (Chi, 1996; Chi, Siler, Jeong, Yamauchi & Hausmann, 2001). The 5-step tutoring frame begins with the introduction of a problem. As indicated by the name, the following five steps are enacted in order:

1. TUTOR asks a difficult question or presents a problem.

2. STUDENT gives an initial answer.

3. TUTOR gives short feedback on the quality of the answer.

4. TUTOR and STUDENT have a multi-turn dialogue to improve the answer.

5. TUTOR assesses whether the student understands the correct answer.

Notably, step 4 of the frame typically involves leading questions, which the original authors call scaffolding (Graesser, 1993). Leading questions were mentioned by Vygotsky (1978) as a kind of guidance or collaborative support that could be provided by the "knowledgeable other," so this use of the term scaffolding is more in line with Vygotsky than Wood et al. However, in the terminology of Wood et al., asking leading questions is an instance of marking critical features, one of the six scaffolding functions. Step 4 is just one point of clear alignment, and there are additional alignments between some of the observed tutoring behaviors from both novice tutors (Graesser, 1993; Graesser et al., 1995) and expert tutors (Person & Graesser, 2003) in formal educational domains with the six scaffolding functions. We consider these in turn.

As noted by Wood et al., recruitment to the task seemed to be more necessary for 3-year-olds than later ages. Accordingly one would expect little recruitment would be needed for high-school or college students. While there is no clear connection to recruitment with the 5-step tutoring frame, we note that the use of concrete and motivating examples by expert tutors (Person & Graesser, 2003) may serve as a means of recruitment by virtue of being meaningful, authentic, and culturally relevant. Expert tutors average 26 examples per hour (Person & Graesser, 2003), so if examples serve a recruitment function it may be the case that formal educational domains require ongoing recruitment to the task, even with older students. The scaffolding function of reducing degrees of freedom is more clearly present in the 5-step tutoring frame. During step 4, tutors tend to ask students mainly verification questions and concept completion questions (Graesser & Person, 1994). Concept completion questions, sometimes called prompts, typically query a single noun phrase missing in the student's answer. Concept completion questions can be considered a kind of simplification because, instead of asking the student for the complete answer, the tutor asks the student to fill in part of the answer while providing contextual cues in the question itself to make this task easier. Verification questions may serve to simplify the task to an even greater degree.

Direction maintenance is provided in two ways. It appears that both novice and expert tutors use a curriculum script (Putnam, 1987), a loosely defined ordering of topics, skills, and learning objects that the tutor plans to cover during the tutoring session (Graesser, 1993; Graesser et al., 1995; Person & Graesser, 2003). Expert tutors have also been described as using highlighting, a mode or phase of the tutoring session that redirects the student having trouble with a problem, breaks the problem down, and creates a plan for the student to follow (Cade, Copeland, Person & D'Mello, 2008). Marking critical features appears to encompass both asking leading questions as well as feedback. Leading questions, like hints, typically suggest what the student should be paying attention to or thinking about without providing much additional context, e.g., "What can you say about gravity in this situation?" Feedback may be simple, e.g., "Correct," or elaborated, e.g., "That's correct because gravity acts in a vertical direction."

The fifth function, frustration control, may not be present in more formal educational tutoring contexts. However, several researchers have noticed that both novice and expert tutor feedback tends to be less discriminating than warranted, particularly with regard to incorrect student answers (Graesser et al., 1995; Person & Graesser, 2003). These researchers have proposed that tutors may be trying to maintain student motivation by giving indirect feedback to incorrect answers or by avoiding giving negative feedback at all. Finally, demonstration is evident in novice tutor's splices and summaries (Graesser, 1993; Graesser et al., 1995). Splices are tutor repairs of student's incorrect answers that either partially or completely give the solution to the problem. Summaries are a kind of retrospective demonstration by the tutor, often given when the tutor has decided to move on to another topic. Because they recap the solution steps, they are a kind of demonstration yet distinct from the prospective demonstration described by Wood et al. In expert tutoring, the connection to demonstration is clearer: modeling modes have been identified that are synonymous with demonstration (Cade et al., 2008).

As indicated by the preceding discussion, there does appear to be a correspondence between scaffolding as defined by Wood et al. and naturalistic observations of human tutoring in formal educational domains. This is perhaps surprising because the original context of scaffolding, blocks puzzles, is clearly informal and bears little superficial resemblance to formal educational tasks. Indeed, at a deeper level, there seem to be significant differences in terms of prior knowledge and abstract operations. However, it appears that the scaffolding functions defined by Wood et al. are still relevant. We argue that this is additional evidence that scaffolding is a theoretically well-defined phenomenon rather than a metaphor.

Scaffolding: Implications for Intelligent Tutoring Systems

In this section, we describe later developments in Wood et al.'s theory of scaffolding and how these correspond to theoretical and actual implementations in intelligent tutoring systems. We argue both the original theory of scaffolding and some implementations of ITSs have failed to incorporate parallel developments of scaffolding falling under the umbrella of cognitive apprenticeship (Collins et al., 1991). We further argue that the notion of "making thinking visible," as championed by cognitive apprenticeship, is a significant advancement of scaffolding in formal educational domains where much of the problem space is covert.

It appears that the theory of scaffolding outlined in Wood et al. (1976) remained unchanged in the following decade. Later developments saw a reframing of the notion of scaffolding in terms of contingency (Wood & Wood, 1996a, 1996b; Wood & Wood, 1999; Wood, 2001, 2003). In many ways, this notion of contingency is an elaboration of the Wood et al. (1976)'s notion of a tutor consulting both a student and domain model when making decisions about what to do next. The overarching premise is that tutor guidance and collaboration should be closely calibrated to the current needs of the student, no more or less. Perhaps the clearest explanation of the theoretical framework of contingency is given in Wood (2003), which defines three dimensions of contingent tutoring:

Instructional contingency: How to support activity

1. General verbal intervention
2. Specific verbal intervention
3. Specific verbal intervention plus nonverbal indicators
4. Prepares for next action
5. Demonstrates action

Domain contingency: What to focus on next (both at the problem and step level)

Temporal contingency: If and when to intervene

Of the three types of contingency, instructional contingency has been the best theoretically developed. In simple terms, it defines a degree of specificity in the tutor's actions, ranging from vague to highly specific. The other two forms of contingency Wood (2003) appears to feel are resistant to further specification, noting that domain contingency is domain-dependent and dynamically grows with the tutor's experience and that temporal contingency is difficult to specify because it is unclear how long one should wait for a student to struggle before offering help.

Although Wood (2003) doesn't explain exactly how the six scaffolding functions of Wood et al. (1976) fit into the notion of contingency, there appear to be a number of correspondences. As discussed earlier, all of the six scaffolding functions may be related to verbal tutor actions in naturalistic tutoring in formal educational domains. Two of the six scaffolding functions, recruitment and frustration control, don't directly relate to instruction in the context of problem solving, however, but rather relate to keeping the student in a state of readiness for instruction. Therefore, it seems that the remaining four scaffolding functions that do relate to instruction in the context of problem solving can each be calibrated according to the specificity of the tutor's action, whether it be reduction in degrees of freedom (the number of degrees reduced), direction maintenance (the specificity of direction given), marking critical features (the specificity with which features are marked), or demonstration (whether a partial, complete, or idealized demonstration is given).

Wood's later focus on contingency seems intermingled with the desire to implement scaffolding and contingency in ITSs (Wood, 2001). One of these tutors, called QUADRATIC, exhibited only instructional contingency, not domain or temporal contingency (Wood & Wood, 1999; Wood, 2001, 2003). All students proceeded through a fixed sequence of problems (eliminating domain contingency) and assistance was only provided in response to student's help requests (eliminating temporal contingency) though the help was calibrated to the individual student (thus having instructional contingency). An evaluation of QUADRATIC revealed that while low-ability students sought help more often that high-ability students overall, high-ability students were more likely to seek help after they made an error than low-ability students. Another tutor, DATA, included both domain contingency and instructional contingency but not temporal contingency (Wood, 2001). Domain contingency was achieved by using a pretest to identify specific categories of errors students were making, and then assigning problems during tutoring based on each child's error pattern. A corresponding evaluation of DATA showed that by including domain contingency, the help-seeking behavior of low- and high-ability students equalized.

We argue that when considered in the context of the original theory of scaffolding, these results are expected: given a set of problems within the ZPD of high-ability students, it is likely that these problems are outside the ZPD of low-ability students because they cannot comprehend the solution, even when it is demonstrated to them. As such, these experiments provide additional support to the original theory of scaffolding. These contingency theory tutors are interesting in another regard: they have conceptual overlap with the ACT* based ITSs as noted by Wood and Wood (1996b). Specifically, the contingency theory and scaffolding overlap with the eight principles for the design of Cognitive Tutors derived from the ACT* theory (Farrell, Anderson, Reiser & Boyle, 1987; Anderson, Corbett, Koedinger & Pelletier, 1995):

1. Represent student competence as a production set
2. Communicate the goal structure underlying the problem solving
3. Provide instruction in the problem-solving context
4. Promote an abstract understanding of the problem-solving knowledge
5. Minimize working memory load
6. Provide immediate feedback on errors
7. Adjust the grain size of instruction with learning
8. Facilitate successive approximations to the target skill.

As noted by Wood and Wood (1996b), Principles 2, 3, 6, and 8 are conceptually linked to contingent tutoring. We briefly elaborate on Wood and Wood's analysis to further show the linkages to the original theory of scaffolding. Taking place within a problem-solving context is what makes contingent tutoring possible. It is not a scaffolding function but is instead a necessary condition for scaffolding to occur. Communicating goal structure is somewhat akin to direction maintenance, though without the affective components. Providing immediate feedback on errors is a means of marking critical features. Finally, facilitating successive approximations to the target skill is not a scaffolding function but rather the contingency at the heart of scaffolding. Successive approximations must imply a reduction in tutor support. In addition to these principles noted by Wood and Wood, we further argue that both minimizing working memory load and adjusting the grain size of instruction parallel the scaffolding function of reducing degrees of freedom.

The comparison with Cognitive Tutors is fruitful because it brings into focus some striking ways in which they differ from contingent tutors, further suggesting avenues of future development for both Cognitive Tutors and contingent tutors. The two ways that contingent tutors differ from Cognitive Tutors are in communicating the goal structure and in promoting abstract understanding of problem-solving knowledge. Above we noted that communicating goal structure was akin to direction maintenance. While this is true, direction maintenance is more aligned with keeping the student focused on a goal, which can happen as a side effect of communicating goal structure. However, communicating goal structure implies much more. The idea behind communicating goal structure is to help the students acquire the ability to decompose goals into subgoals on their own. In the case of learning to write recursive programs (Farrell et al., 1987), the goal structure can be covert. Promoting abstract understanding of problem-solving knowledge is similar in that it invokes the underlying structure rather than surface structure (Anderson et al., 1995). In both cases, the knowledge the student needs is not overt, so extra care is taken to help the student acquire it. It's worth noting that Anderson et al. (1995) implemented communicating goal structure by providing interface elements like graphs to communicate the structure, and they promoted abstract understanding of problem-solving knowledge through help and error messages. We would argue that these implementations of the principles are rather weak in terms of contingency.

The notion of making the covert overt in the context of scaffolding has been championed in the framework of cognitive apprenticeship (CA) (Collins et al., 1991). A full review of CA is beyond the scope of this chapter, but we briefly remark on its similarities and differences to the original theory of scaffolding. First and foremost, CA casts learning as the development of expertise, with teachers as the experts. Just as in traditional apprenticeship, where the apprentice eventually becomes a master, CA views cognitive apprenticeship as a process by which students can become experts. The first step in enacting CA is to "identify the processes of the task and make them visible to students" (Collins et al., 1991, p. 3). This specifically involves communicating an expert's reasoning and strategies. Expert reasoning and strategies are a crucial missing component to Wood et al. (1976)'s scaffolding. Their scaffolding focused on problems and skills and made no mention of strategies. The omission of reasoning and strategies might have resulted from the domains investigated, which allowed little room for such strategies. Similarly strategies are poorly represented in later work on contingent tutoring. While this work discusses how contingent tutoring may lead students to discover and use strategies by induction, it says nothing about making expert reasoning and strategies visible to students (Wood, 2003). We argue that CA addresses communicating goal structure and abstract understanding of problem-solving knowledge proactively, and proactively addressing these principles in intelligent tutoring systems should yield similar benefits as found elsewhere (Palincsar & Brown, 1984; Schoenfeld, 1985).

Conclusion

In summary, we have analyzed the notion of scaffolding from its genesis to the modern conception of the term. We argue that scaffolding today, which is widely considered a metaphor for support, ignores the most useful and productive theoretical aspects of the original theory. Scaffolding has clear correspondence to and elaborates upon the ZPD. It adds a great deal of clarity to that term by recasting it in terms of the gap between comprehension and production. Scaffolding, though originally defined for small children working on blocks puzzles, has proven to be sufficiently general to accommodate findings from observations of naturalistic tutoring in formal educational domains. However, scaffolding as originally defined may require modeling that is too fined grained for a teacher to implement in a classroom. Further developments in the original theory of scaffolding have added more abstract descriptions of contingency, but these have not replaced the original theory. Indeed the original theory has multiple points of intersection with the principles derived from ACT* that were used to develop the Cognitive Tutors. What is missing from the original theory of scaffolding, and what is also underdeveloped in the principles derived from ACT*, is a proactive approach to supporting the development of expert reasoning and strategy use. CA outlines a framework for making thinking visible in order to support development of expert thinking and strategy use. We argue that scaffolding should move beyond "modeling a solution" to include "modeling a strategy." Only then will scaffolding directly support the learning of hidden goal structures and abstract problem-solving knowledge. In other words, we argue that the most effective scaffolding makes expertise visible.

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