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# Scaffolding in Technology-Enhanced Learning Environments

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Scaffolding has proven an especially interesting and promising area for supporting teaching and learning practices. Particular interest has emerged in scaffolding student learning in technology-enhanced environments. In this paper, we discuss how scaffolding is implemented in technology-enhanced environments, provide an overview of scaffolding processes and techniques in various contexts, and then provide empirically based guidelines for designing scaffolding in technological environments. We examine current research to identify two primary design components, cognitive and interface, and suggest how scaffold design might be improved for more effective use by learners. We conclude by identifying practice and research implications.

## Introduction

Metaphorically, scaffolding refers to expert support for a novice's learning. Early scaffolding research delineated interactions between expert and novice in the learning process (see for example, Wood, Bruner, & Ross, 1976); subsequent research has focused on student learning (Graves & Braaten, 1996; Palincsar, 1986; Rosenshine & Meister, 1992), experts' strategies during a scaffolding interaction (Applebee & Langer, 1983; Hogan & Pressley, 1997; Palincsar, 1986; Wood et al., 1976), and characteristics of the ideal "tutor" or expert scaffold (Lepper, Drake, & O'Donnell-Johnson, 1997; Merrill, Reiser, Ranney, & Trafton, 1992). These investigations have yielded well-grounded design guidelines for scaffolding learning in traditional environments (see for example, Bliss, Askew, & Macrae, 1996; Hogan & Pressley, 1997; Palincsar, 1986).

The role of scaffolding in technology-enhanced learning environments (TELEs) is of considerable interest to both educators and researchers; definitions and conceptualizations, however, have proven elusive (e.g., Ge & Er, 2005; Pea, 2004; Puntambekar & Hübscher, 2005). TELEs differ from traditional environments in their use of computers to direct and enhance learning. In typical technology-based environments, scaffolding design has been guided by expert understanding of how best to support a novice's learning. While this is important, scaffolding design and

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implementation must also account for both learner characteristics and contextual influences.

Understanding the learner's role is vital to augmenting expert-novice dialogue related to learning goals (Rogoff & Wertsch, 1984; Wertsch, 1984). The expert human customizes support to changing learner needs. In face-to-face learning environments, dynamic scaffolding obviates the need for a priori understanding since joint understanding is negotiated. However, dynamic negotiation is difficult to replicate in TELEs. In TELEs, Lumpe and Butler (2002) conceptualize this process as an interaction between the learner and software that provides scaffolding. From this perspective, learner perceptions define quality and level of scaffolding usage. Thus, design of effective TELE scaffolding requires consideration of a learner's ability to *interact with and use* scaffolding tools.

In this paper, we review TELE scaffolding research and theory, distill learner characteristics and contextual conditions that affect scaffolding interactions, and identify implications for design of TELE scaffolds.

## Delineating the Scaffolding Interaction

Scaffolding has been characterized traditionally as a process during which an expert supports learner accomplishment of a specific task or attainment of a specific goal (Wood et al., 1976). The expert gradually fades support as learner competence increases. Initial research in scaffolding explored the nature of parent-child interactions and the role of an adult teacher in supporting a young child's learning (see for example, Rogoff & Wertsch, 1984; Saxe, Gearhart, & Guberman, 1984; Wood et al., 1976).

Scaffolding was initially conceptualized as a process of adult-child interaction that focused on task completion. As the metaphorical use of scaffolding became popular, it was compared to the zone of proximal development (ZPD) – the difference in a learner's developmental level as measured by independent and collaborative problem solving (Vygotsky, 1978). Wood (1980) noted:

> The adult provides just that level of intervention which [sic] is necessary to get the child over his current difficulties; when the learner can successfully take the responsibility for a particular constituent of the task, the adult abandons that particular form of intervention and reacts at a more general level. (p. 294)

The links between scaffolding and ZPD provide conceptual and operational frames for design and study. Both constructs involve interactions between an expert (i.e., teacher) and a novice (i.e., learner), where the expert assists the novice in performing a specific task. Scaffolding, therefore, operationalizes Vygotsky's relationship between instruction and psychological development. The ZPD thus supplies a conceptual framework for selecting individual learning tasks, while scaffolding provides a strategic framework for selecting and implementing strategies to support specific learning.

The linking to ZPD also extended early conceptions of scaffolding to include interactions where experts support novices by providing, and then fading, support. The focus of scaffolding task completion was subsequently broadened to include support for learning in general (see for example, Bliss et al., 1996; Hogan & Pressley, 1997; Palincsar, 1986; Roehler & Cantlon, 1997). Learning could be viewed as first occurring through the interaction between expert and novice, that is, as initial development of higher level psychological processes on the interpersonal level, followed by learner internalization and independence (Roehler & Cantlon, 1997). Scaffolding supports the learning and development of independent skills by facilitating successive levels of competence (Palincsar, 1986). When the learner demonstrates an acceptable level of competence, the scaffold is withdrawn to promote independent functioning.

While scaffolding refers to expert support, it is conceptually and operationally distinguishable from other types of assistance because it is faded. Fading, the gradual reduction and eventual elimination of scaffolds, has been identified as a key distinction between scaffolding and other forms of support. Lepper, Drake, and O'Donnell-Johnson (1997) equated scaffolding with the temporary structures that assist with construction of an arch or bridge: When the scaffolding is removed, the structure continues to stand unsupported. Lepper et al. highlighted three significant aspects of a scaffolding interaction: (a) It supports learners in the achievement of tasks beyond their unassisted capacity; (b) when the support structure is removed, learners continue to function competently on their own; and (c) removing the support structure does not reduce learning or functioning – instead, learners continue to function at the elevated plane reached via scaffolding.

Thus, scaffolding interactions may be distilled into the provision and withdrawal of expert support. For the purpose of this paper, scaffolding is defined as *a two-step process of supporting the learner in assuming control of learning and task completion.* First, the expert provides the novice with appropriate support to identify strategies for accomplishing individually unattainable learning goals or tasks. In the second step, the expert gradually fades this assistance as the learner becomes increasingly competent. Thus, scaffolding is characterized by continuous and constructive interactions between experts and learners as they work collaboratively to shift the locus of responsibility for task completion and learning from the expert to the learner.

## Instantiating Scaffolding in Technology-Enhanced Learning Environments

In TELEs, scaffolding can be conceptualized as the provision of technology-mediated support to learners as they engage in a specific learning task. Technological scaffolds can provide procedural and metacognitive support for routine tasks, and thereby support learning in classrooms. Contemporary learning contexts incorporate several support mechanisms and are often characterized by multiple students with a single teacher, who due to temporal and contextual exigencies often scaffolds the learning of groups of students (e.g., Puntambekar & Kolodner, 2005). In such cases, technology can assume some routine support tasks and allow the teacher to provide dynamic support. Technology affordances can also enhance scaffolding interactions by offering unique representational opportunities, and varied means for exploring ideas and concepts (Saye & Brush, 2002). As a motivation tool, technology-enhanced scaffolding can attract and retain attention for a variety of users, including younger children (Shute & Miksad, 1997). By distributing extraneous cognitive load to the computer, learners and experts can both be freed to concentrate on rigorous higher order reasoning.

Several aspects of TELE scaffolding development are akin to face-to-face scaffolding, such as planning for task and scaffolding strategy selection. The expert must identify appropriate tasks for learner engagement, that is, tasks that are neither too difficult nor too easy, and that can be achieved with assistance (see for example, Applebee & Langer, 1983; Bliss et al., 1996; Gaffney & Anderson, 1991). Technological scaffolding must be designed according to learners' developmental and cognitive needs for the specific instructional context. For example, Beyer (1997) noted that directive scaffolding is often appropriate for young children and domain novices, while mature learners are better able to engage in Socratic scaffolding, such as questioning and reflecting. Likewise, scaffolding procedural and skill-based learning differs from analytical and metacognitive learning.

However, technology-enhanced scaffolding also differs from face-to-face, traditional interactions. Software constraints often limit dynamic scaffolding to interactions that can be anticipated in advance. Thus, TELE scaffolds are often static and do not change dynamically as individual circumstances evolve. In addition, when mediated by technology, fading may be triggered by pre-established criteria, and thus be less responsive to emerging needs.

### *Hard and Soft Scaffolds*

Scaffolding research and practice suggests that technology can consistently support procedural tasks or provide standard prompts for metacognitive processing. Some researchers suggest that logistical and conceptual difficulties render technological tutors incapable of mimicking human tutors (Farquhar & Orey, 1997; Merrill et al., 1992). To be sensitive to individual learner needs, software must be programmed to include an exhaustive list of options and paths, which is a monumental logistical undertaking. Conceptually, designers must anticipate learner needs a priori to develop appropriate support. Thus even with large investments of time and resources technological tutors cannot provide as sensitive and customized support as a human tutor can. As an alternative to complete customization, Saye and Brush (2002) suggest using hard and soft scaffolds in TELEs: Hard scaffolds are fixed, non-negotiable, and primarily technology-mediated; soft scaffolds are provided by an expert and are customized and negotiable. Hard scaffolds help to support common learning needs, freeing the instructor to provide on-demand, contextually sensitive soft support. However, hard scaffolding may also engender dependence, impeding ownership of and responsibility for one's own learning (see for example, Oliver & Hannafin, 2000), and thus provision of scaffolding may be balanced by the use of implicit scaffolds.

Hadwin and Winne (2001) distinguished between explicit (more directive) and tacit (less directive) scaffolds. In CoNoteS2, a scaffolded software tool designed to support note taking and self-regulation, tacit scaffolds comprised a set of tools from which students could choose. Explicit scaffolds functioned as templates that focused student attention by identifying and requiring students to use specific processes. Balancing imposed and elective scaffolds has proven challenging, as learners often lack the requisite decision-making knowledge or skill. Pea (2004) described a need for ‘‘metascaffolding’’ to support learners in selecting appropriate supports and this function can be easily performed by a teacher or other facilitator.

## Re-Conceptualizing and Instantiating TELE Scaffolding

It is important to clarify how scaffolding is conceptualized in TELEs. As suggested previously, research suggests that computers are often unable to provide scaffolding appropriate to a given student’s developmental and learning level. While scaffolding has been reduced at predetermined points based on specific algorithms, fading has rarely been predicated on an individual’s needs or performance. Fretz et al. (2002) suggested that computer-based scaffolds might be designed with the *capacity to be faded*, but that they need not necessarily be faded during successive iterations. Such scaffolds can be embedded within a learning context and fading can be determined by a human expert based on assessment of learner performance.

Given that computer-based scaffolds cannot easily match the sensitivity of a human expert, how can they be designed to scaffold learning in a classroom context? One option is to design technological scaffolds to provide specific assistance in conjunction with other scaffolds, since different types of support may be warranted to meet the developmental needs of learners. Puntambekar and Hübscher (2005) suggested that the redundancy afforded by distributed scaffolds, multiple scaffold types that support a single performance, provides additional opportunities for diverse learners to benefit from scaffolding. Effective scaffolding requires accommodating differences in understanding for a specific task and creating tools and agents to address individual needs (see also Tabak, 2004). Thus, designers must consider the specific affordances of computer-based scaffolds and their effective integration within a learning context. For example, multiple types of scaffolds may be designed to address varied developmental levels and address levels of granularity: As students progress toward independent performance, detailed scaffolding may be faded initially followed by fading increasingly general scaffolding (Puntambekar & Kolodner, 2005).

Sherin, Reiser, and Edelson (2004) recommend considering both goals and contexts when designing scaffolds. In dynamic environments, scaffolding may integrate synergistic tools and agents, including curricular materials, resources, peers, and teachers. Software scaffolds may support a range of performance and learning tasks within the overall environment. According to Tabak (2004), differentiated scaffolds support varied needs by providing multiple supports via multiple means.

Redundant or distributed scaffolds target a single learning need and provide graduated support through different means and at different stages in the process. Synergistic scaffolds support a single need through multiple, co-occurring and interacting supports. Thus, software scaffolds, when considered within an inclusive environment, can be the sole support for a specific task or one aspect of group of scaffolds that address common needs.

Pea (2004) suggested that designers carefully examine the purpose of scaffolding tools and then decide whether to fade. A variety of technological tools currently support execution of various tasks, and if a scaffolding tool is an inherent component in the performance of a specific activity, fading may prove unnecessary and unproductive. Calculators, for instance, could be considered scaffolds in that they support the ability to perform calculations and mitigate unnecessary cognitive load. However, the use of calculators might be considered an embedded practice within a community of mathematicians. Thus fading of calculator use may not serve a useful purpose and may actually impede the learner's ability to engage in and develop sophisticated forms of reasoning (Pea, 2004). Conversely, if scaffolding needs to support the internalizing of a specific process or task, it would necessarily be faded since the learner must demonstrate the performance autonomously.

### *TELE Scaffolding in Practice*

TELE scaffolding can support a range of learner needs. Two important affordances of computer systems are the ability to constrain user actions through predefined rules and the ability to store large amounts of data. By directing attention on important task features, software scaffolding may prevent learners from engaging in unnecessary, misleading, or unproductive tactics (Pea, 2004). In Cho and Jonassen's (2002) study of supported students argumentation during ill-structured problem solving, for example, certain learner responsibilities were controlled by the system. In order to constrain argument construction, students were cued to important information by a software tool that provided a framework for organizing arguments. The software provided four types of predefined conversational nodes (data, hypothesis, principle, unspecified) to constrain the dialogue. In addition, the software constrained the types of links between specific nodes with specific connectors (for, against, and) to support student construction of valid arguments. Reiser (2004) suggests that providing direction or narrowing choices allows learners to manage their planning and task execution, thereby focusing on important criteria and goals. The design of such software scaffolds is facilitated by focusing on common learner misunderstandings or difficulties to constrain the range of problem solving or task performance options.

TELE scaffolds can also formalize expert reasoning processes and make them accessible to learners in different ways. In contrast to Cho and Jonassen, Shabo, Guzdial and Stasko's (1997) scaffolding expanded availability to various expert strategies, allowing students to engage problems from multiple, viable perspectives. Their expert-centred approach involved communicating the process, coaching, and eliciting novice articulation on the process. Thus, the software scaffolds included case libraries, course notes, and a series of interactive exercises including multiple solutions and visualizations of problem responses. Per expert scaffolding functions, students could access multiple expert interpretations of a single topic or expert views on various strategies for problem solving, and engage in discussions with peers using the provided software. Accordingly, scaffolding design might focus on expert processes or pedagogical tactics proven successful in supporting student learning. Shabo, Guzdial and Stasko's approach situated learning in authentic, ill-structured contexts and allowed learners to engage with experts' discourse, tools, and reasoning in specific subjects (e.g., Quintana et al., 2004; Reiser, 2004; Tabak, 2004).

To design effective software scaffolds, Lumpe and Butler (2002) suggest a process-centred approach that focuses on the interaction between students and tools. Thus, their approach suggests a more inclusive definition that requires simultaneous consideration of design and use. This approach is consistent with basic principles of interface design and design-based researchers, where early user involvement leads to more consistent and usable design: Scaffolds must be based on valid learning principles and design strategies; approaches may be modified based on use and perceptions of the tools.

## Implications for TELE-Based Scaffolding

Scaffolding research and practice has focused on two distinct yet complementary design components: *Cognitive* design explicates and communicates underlying thinking processes and products in the achievement of a learning goal, while *interface* design focuses on representational formats that accurately and efficiently convey the cognitive intent of the scaffolds. Table 1 summarizes key design considerations for scaffolds.

### *Make Cognitive Processes Explicit*

Scaffolding in TELEs needs to clarify the procedures and metacognitive reasoning required to complete a learning task (Masterman & Rogers, 2002). The strengths of software scaffolding in instances cited below include the ability to provide consistent support and clarification about basic procedural and metacognitve aspects of a learning task, which can then be augmented and customized by the human expert.

*Explicate process using procedural scaffolds.* By emphasizing specific sequences, procedural scaffolds provide models of thinking while mitigating extraneous cognitive load. In ill-structured, complex situations, scaffolding should allow students to move through required activities in a non-sequential, iterative fashion. In their research with software scaffolds for science learning, Quintana, Krajcik, and Soloway (2002) provided two mechanisms to scaffold student non-sequential engagement. In one option, students were provided tabbed workspaces, which enabled them to circulate non-sequentially among multiple workspaces. In the other option, students were provided a planning interface similar to a management timeline, which listed activity

Table 1. TELE Scaffolding design considerations

| Primary considerations | Implication | Empirical evidence | Software scaffolds |
|---|---|---|---|
| Make cognitive processes explicit | • Explicate process using procedural scaffolds (i.e., provide models of thinking to mitigate extraneous load) | • Provide access to visualizations of a range of activities and sequences for reaching a goal (Quintana et al., 2002) | • To support iterative non-sequential task engagement, the software provided students with tabbed workspaces and a timeline. Clicking on the tabs or points on the timeline allowed students to switch between non-sequential tasks. |
| | | • Focus student attention on important tasks (Shabo et al., 1997) | • Structured exercise screen presented with aspects of the problem defined. Windows linking to additional notes, visualization tools, and learning paths available from the exercise screen. |
| | • Make understanding visible by using metacognitive scaffolds (i.e., communicate underlying reasoning) | • Clarify important reasoning underlying the process and output (Hadwin & Winne, 2001; Saye & Brush, 2002; Zembal-Saul et al., 2002) | • Saye and Brush's used storyboard template screen with three text windows, where students were prompted to add specific information to demonstrate reasoning on social problems. |
| | | • Provide opportunities for students to clarify and externalize their | • Students provided a text box to document understanding during problem solving. |

(*continued*)

Table 1. (*Continued*)

| Primary considerations | Implication | Empirical evidence | Software scaffolds |
|---|---|---|---|
| | | misunderstandings (Davis & Linn, 2000) | Students could select windows with hints and notes on specific topics under study. |
| | | • Provide specific scaffolds to address common misconceptions (Zembal-Saul et al., 2002) | • Design recommendation – Development and research opportunity. |
| | • Balance metacognitive and procedural scaffolds | • Provide process prompts to support task achievement, but be aware that it may encourage a piecemeal approach to learning (Davis & Linn, 2000) | • Screen windows provide activity prompts, are in the form of sentence openers: "The major claims made by the article are…", "The first claim we critiqued was…", all of which facilitate task completion. |
| | | • Provide metacognitive prompts, to support externalization of thoughts but be aware that tasks may not be completed (Davis & Linn, 2000) | • Window prompts in the form of sentence openers: "Pieces of evidence we didn't understand very well…", "In thinking about how it all fits together we are confused about…". |
| | • Account for learner characteristics | • Consider individual motivation and need for domain, strategic, and metacognitive knowledge (Lumpe & Butler, 2002) | • Design recommendation – Development and research opportunity. |

(*continued*)

Table 1. (*Continued*)

| Primary considerations | Implication | Empirical evidence | Software scaffolds |
|---|---|---|---|
| | | Consider differential impact of scaffolds on different students (Davis & Linn, 2000) | Design recommendation – Development and research opportunity. |
| | Account for learner expectations of task | Consider students' expectations of the scaffold in supporting existing strategies and skills (Hadwin & Winne, 2001) | Design recommendation – Development and research opportunity. |
| | | Consider that different expectations of task will result in different uses of scaffold (Sharma & Hannafin, 2004; Zembal-Saul et al., 2002) | Sharma and Hannafin provided students an online document listing probe questions to articulate their reasoning about design. Despite these templates, students used them differently. |
| Use appropriate representations | Integrate contextually appropriate scaffolds | Provide embedded contextual scaffolds to improve student performance (Saye & Brush, 2002) | Students were provided hyperlinks to resources (newspaper articles, photos, videos) presenting contradictory and supporting evidence to encourage critical reasoning. |
| | Use scaffolds sensitive to learner assumptions, needs, and differences | Textual and graphical scaffolds offer the same advantages (Quintana et al., 2002) | Design recommendation – Development and research opportunity. |

(*continued*)

Table 1. (*Continued*)

| Primary considerations | Implication | Empirical evidence | Software scaffolds |
|---|---|---|---|
| | | • Consider how graphics constrain the inferences (Masterman & Rogers, 2002) | • Design recommendation – Development and research opportunity. |
| | • Ensure scaffold visibility and utilization | • Provide visible and essential scaffolds to support student performance (Quintana et al., 2002) | • Students were provided individual screens providing multiple text boxes that prompted activities (e.g., how to visualize data and the process for creating different visualizations). |
| | | • Demonstrate scaffold function (Quintana et al., 2002; Saye & Brush, 2002; Shabo et al., 1997) | • Instructor provides orientation to software at the beginning of session. Development and research opportunity for software scaffold design. |
| | • Ensure appropriate modelling | • Student use of scaffolding maps instructor demonstrations of tool (Abbas, 2001) | • Development and research opportunity for software scaffold design. |
| | | • Support hard scaffolding with customized instructor scaffolding (Fretz et al., 2002; Saye & Brush, 2002) | • Practical recommendation based on research. |

names and completion times. By selecting a specific activity cell, students were able to engage in multiple activities in any sequence. In this instance, access to multiple representations enabled students to better visualize ill-structured problems as recursive and randomly sequenced. Thus, software scaffolding presented a specific model for visualizing procedures. The strength of software scaffolding in this instance lies in its ability to simultaneously support multiple students to engage in a variety of representations of the problem and to reinforce task procedures. As an example, it is likely that students who were comfortable with more structured guidance would find the timeline helpful, while other students could choose the more unstructured, reiterative, tabbed approach. Especially when multiple options are presented within an unstructured context, software scaffolds are useful for structuring and constraining student navigation in the problem space, whereas more customized support might be provided by a human expert.

In an effort to mitigate confusion by focusing student attention, Shabo et al. (1997) provided both unstructured case libraries and well-structured exercises with accompanying resources. Due to the amount of information and a lack of structure for appropriate usage sequence, students initially encountered difficulties using unstructured case libraries. However, interacting via structured exercises improved use of multiple resources, such as course notes, exercises, and visualizations. Thus, when presented problems and situations involving multiple resources, procedural scaffolds provide much needed organization, thereby mitigating confusion. The strength of software scaffolding, here too, lies in the ability to guide student actions consistently to avoid cognitive overload.

Especially in information intensive contexts, procedural structures are important to focusing and sustaining student activity. In an investigation into use of *Artemis* – a Web-based digital library that allows searching and sorting of science information – students reported organizational features to be most useful (Lumpe & Butler, 2002). During the course of their inquiry, students expressed appreciation about having control of information access and organization as they completed their projects. Lumpe and Butler concluded that organizational scaffolds allowed students to focus on information seeking tasks while avoiding extraneous features.

*Make understanding visible by using metacognitive scaffolds.* Reiser (2004) suggests that scaffolds should problematize student understanding, that is, focus on important disciplinary learning concepts and processes by posing appropriate problems. In such cases, scaffolding can also communicate underlying reasoning and encourage students to contemplate their understanding. The advantage of software scaffolding is the ability to provide consistent levels of basic conceptual support for all students, multiple representations of concepts to convey meaning, and consistent clarification of quality and assessment. Saye and Brush (2002) used metacognitive scaffold templates to enhance reasoning in social sciences. A first template functioned as a storyboard, providing placeholders for specific types of information and resources to be integrated in each screen. The prompts focused attention on the key items needed make persuasive, critical, and dialectical arguments about social issues. The second template was a complete model presentation. That is, students could examine the model presentation and identify the precise logic, resources, and items used to make a persuasive argument. Students then developed a multimedia presentation employing persuasive dialectical reasoning about historical events. Student performance indicated that the templates improved students' ability to identify the format, reasoning, and process behind the final product. The "hard" scaffold templates helped to focus student attention and make explicit the important aspects of both the process and expectations. Provision of the hard scaffolds also ensured that a consistent, basic level of support was provided to every student, and that additional "soft" scaffolding could build on this initial level of conceptual and procedural learning.

The consistent provision of metacognitive scaffolds may also allow students to clarify procedural or conceptual misunderstandings, which have been shown to hinder learning. In Davis and Linn's (2000) study of science learning, 8th-grade students were provided with activity and self-monitoring prompts through software. Metacognitive prompts were introduced to help students identify incomplete understanding. Results indicated that while some students provided superficial responses to the prompts, identifying only the topic of misunderstanding, others provided elaborated explanations of their misunderstanding. Students who elaborated their misunderstanding scored significantly higher scores on their final project and were more likely to develop integrated scientific understandings. The consistent reminders provided by the software scaffolds thus aided students in their learning.

The utility of metacognitive prompts for externalizing understanding was further demonstrated in Zembal-Saul, Munford, Crawford, Friedrichsen, and Land's (2002) research on pre-service science teachers' use of software scaffolds to construct scientific arguments consistent with discipline-specific conventions. Their research indicated that despite scaffolding, students adhered to their prior conceptions of the content, especially when a mismatch was perceived between their understanding and the intent of the scaffolds. In addition to scaffolding reflection to externalize misunderstandings, Zembal-Saul et al. suggest the use of specific process and metacognitive scaffolds based on known misconceptions or common errors. Thus, directive scaffolds may help to explicitly correct misunderstandings, while non-directive scaffolds may trigger metacognitive exploration of understanding.

*Balance metacognitive and procedural scaffolds.* Davis and Linn's (2000) research with activity and self-monitoring prompts indicated the need for balancing scaffold types. In the first phase, students given only activity prompts were more likely to provide directly relevant, descriptive scientific explanations, however, they failed to integrate scientific principles in their explanations. Thus process prompts supported task *achievement*, but engendered piecemeal approaches. In the second phase, one group received only metacognitive prompts while the other received only activity prompts. Their findings indicated that students receiving self-monitoring prompts alone were less likely to complete all aspects of the project. Thus, balancing process and metacognitive prompts was most likely to support activity completion as well as the underlying reasoning being scaffolded. Developing mechanisms to present proportionate amounts of software-based metacognitive and procedural scaffolds is an important area for investigation.

*Account for learner characteristics.* Lumpe and Butler (2002) suggest that scaffolding must account for the individual's motivation as well as the need for domain, strategic, and metacognitive knowledge. The authors attributed variations in scaffold use by students to differences in learning styles and cognitive overload. Similarly, Davis and Linn (2000) used metacognitive prompts to help students reflect: The same prompt generated detailed discussions from some students but superficial responses from others. The different reactions to the prompts were attributed to differences in perceived needs for reflection. Thus, detailed responses were more likely from students who valued reflection than from those who did not. Consistent with research on the importance of self-explanation and reflection in augmenting understanding (Chi, de Leeuw, Chiu, & LaVancher, 1994), Davis and Linn noted that students who perceived a need for reflection were generally more successful in completing tasks than students who did not. A unique attribute of software in such an instance is its ability to assess and tailor presentation of scaffolds according to student profiles. Developing systems that address variations in student expectations and interests, and provide appropriate support is another fruitful avenue for development and research.

*Account for learner expectations.* To support students' study skills, Hadwin and Winne (2001) developed a scaffolded note taking application, which included templates for important note categories. Their initial evaluation indicated that the effort involved in note taking via computers was considered greater than familiar, traditional approaches. In addition, students found that the note taking tool did not support their existing strategies and skills; thus, dissonance between expectations of the task and the tool's capabilities reduced their efficiency (Hadwin & Winne 2001, p. 329). Likewise, in Zembal-Saul et al.'s (2002) study, scaffolding designed to support and structure scientific explanations included generating evidence and building arguments. One student pair formed a demonstrably incorrect hypothesis and proceeded to use the software to corroborate the erroneous hypothesis. In contrast, another pair of students used the scaffolds to disprove their initial hypothesis as well as to explore evidence to develop, test and validate alternative hypotheses and explanations.

Other researchers have found scaffold use to be influenced by assumptions of purpose. In an online course designed to enhance critical thinking about instructional design, learners were provided Socratic question scaffolds to encourage deeper examination and justification of design strategies. Some learners used the scaffolds to guide their thinking, while others used them prescriptively to define instructor requirements (Sharma & Hannafin, 2004). Students who used the scaffolds as a template exhibited reflective understanding of the course content and processes, while students who used scaffolds prescriptively exhibited superficial, task-specific approaches. It is essential that design of software scaffolds be guided by investigations into student assumptions of the task and process. User-based design approaches might prove especially useful to guide scaffold form and function.

### *Use Appropriate Representations*

Scaffold use is influenced by context, learner-appropriate representations, and the visibility and availability of scaffolds. The challenge for designing software scaffolds is to frame the visibility and utility of scaffolds within the specific use context.

*Integrate contextually appropriate scaffolds.* Learning tasks may require contextually "tuned" scaffolds. In the first version of Saye and Brush's (2002) software, students were presented numerous data categories for a specific topic. While investigating accounts of the African American civil rights movement, students were able to access newspaper accounts, video clips, and interactive essays by specific categories. The researchers noted, however, that students encountered difficulties situating evidence in the context of a specific goal. Thus, in the second version of the software, additional resources (such as videos, newspaper accounts, etc.), consistent with experts' framing of problems and subsequent investigation processes, were hyperlinked directly within the context of an essay. Results indicated that students accessed twice as much supporting information in the contextually appropriate scaffold version as the original version. Thus, integrating scaffolds within the inquiry process allowed students to explore additional resources and strengthen their argumentation (Saye & Brush, 2002). As opposed to making available a choice of scaffold options, the design integrated scaffolds within a conceptual framework, presenting scaffolds when they were logical and useful in the learning process. This important design change increased learner use of scaffolds.

*Use scaffolds that are sensitive to learner assumptions, needs, and differences.* Masterman and Rogers (2002) suggest that computers enable three primary representational opportunities. *Re-presentation* involves using different forms to clarify a single abstract process or concept. For example, a sequence of historical events can be represented in the form of a timeline, a descriptive paragraph, or a table; all three are based on the same underlying abstraction but represent differently. *Graphical constraining* refers to the meaning conveyed by specific graphic devices, such as a timeline indicating linearity. *Temporal and spatial constraining* refers to features such as graphics and animations that can amplify characteristics of time and space. For example, a historical sequence of events can be illustrated in the form of a roadmap. Events can be presented in the form of milestones and animated characters could progress from one milestone to the next to clarify sequence. Such a representation compactly illustrates specific events within temporal and spatial boundaries.

Quintana et al. (2002) suggest that while visual scaffolds have no inherent advantages over textual scaffold representations, format can influence assumptions about scaffold function. Graphical constraining describes how visual elements can limit inferences made about a representation. During their investigation of scientific problems, students used a "process wheel" that graphically identified activities to be used during their investigation. Students initially selected activities in a clock-wise fashion, and performed all activities sequentially regardless of their utility or necessity; in effect, they were unintentionally cued to a sequence. After sustained interaction, students eventually selected activity sequences that were appropriate for their specific problem. The initial clock-wise sequencing was assumed by students based on popular conceptions of circular structures (e.g., wheels, knobs, clocks), and thus tacitly influenced their use of the tool (Quintana et al., 2002). Thus, while computer-based representational opportunities provide powerful mechanisms for communicating concepts, their design must be tempered by an understanding of student assumptions and projected use.

*Ensure scaffold visibility and utilization.* As noted previously, while continuously visible scaffolds can engender dependence, research on student use of *Symphony* scaffolds indicated that students mainly used visible and "essential" scaffolds. Although students consistently used scaffolds perceived as closely related and essential to task performance, they rarely used scaffolds perceived as peripheral to task performance (Quintana et al., 2002). Thus, scaffolds – whether procedural or metacognitive – need to be both immediately available and apparently relevant to task completion. Software design must thus consider how to effectively and visibly present scaffolds on screen within the relevant context.

While visibility influences whether students trigger scaffolds, it does not necessarily promote appropriate usage. Students may misunderstand the purposes of scaffolds resulting in inconsistent usage or non-usage (Oliver & Hannafin, 2000), or students may perceive scaffolds as being difficult thus refrain from using them (Hadwin & Winne, 2001). Use is likely to increase when scaffolding tools are explicitly identified and their functions clarified (Quintana et al., 2002; Saye & Brush, 2002). An introduction to purposes and usage, for example, can clarify both why and how students should use scaffolds (see for example, Slotta & Linn, 2000). Commenting on their use of specific features of the program, students stated that while they appreciated the features of the program, they were unsure how to use them appropriately (Shabo et al., 1997). Abbas (as cited in Lumpe & Butler, 2002) found that teacher support and explanations were critical in guiding students' use of scaffolding. Thus, ongoing support and initial orientation sessions are critical to supporting use and increasing familiarity of scaffolding tool. Another option might include designing software-based elaborations of scaffold use, such as pop-up windows or rollovers, to indicate utility and importance for the learning task.

*Ensure appropriate modelling.* Software-based scaffolds may minimize extraneous cognitive load for students, but in practice they are rarely used without "live" support (Shabo et al., 1997). During a pre-service teacher education course, where multiple experts' case knowledge for teaching was scaffolded using an online case-based reasoning tool, students still relied extensively on the "live" instructor for insight and guidance (Kim, 2005). In Saye and Brush's (2002) study, while students employed software to reason about social problems, the instructor provided additional live support by examining students' work and posing probing questions about their reasoning and analysis. Instructor and peer scaffolding may be especially helpful when students are hesitant or unsure about the use of technology-based scaffolds (Fretz et al., 2002). For example, Abbas (2001) found that student use of a Web-based interface for science learning closely matched how teachers demonstrated the interface.

## Conclusion

Technology-based scaffolds can support individual students by communicating a range of processes and cognitive activities, and simultaneously freeing the teacher to focus on dynamic, customized scaffolding. In technology-enhanced environments, tools and agents support some roles traditionally assumed by tutors or experts. It is important, however, to note that such scaffolds are integrated within a dynamic, complex environment often featuring a wide range of resources and artifacts.

Carefully crafted scaffolds may promote both task completion and reasoning skills; they may also inadvertently misdirect students. Scaffolds can support students' efforts to address learning needs and refine their understanding as well as strengthen faulty assumptions or incomplete understanding. While research indicates that students given procedural scaffolds are more likely to complete projects, they are unlikely to consider the process and reasoning holistically without further support. To avoid discrete task-focused performance, procedural-metacognitive scaffolds may help to amplify underlying reasoning. Likewise, scaffolds may provide opportunities for students to deepen their understanding by externalizing and comparing their knowledge and beliefs with those of peers and experts. To engender appropriate use, scaffold design needs to be consistent with learners' understanding and cognitive development. Early evaluation of scaffold design using a learner-centred design process can reduce the possibility of unintended interpretations of a scaffold's intent.

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