Dimensions of scaffolding in technology-mediated discovery learning environments

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Abstract: In this paper, we revisit and re-examine the importance of and possibilities for supporting and scaffolding learner activity, with a particular focus on discovery learning tasks mediated by information and communications technologies. We propose a new framework for classifying scaffolding in technology-mediated environments that consists of two dimensions, the first of which pertains to the type of knowledge development being supported and the second of which identifies the pedagogical technique used to provide the scaffolding. Having introduced our framework, we proceed to describe examples that illustrate the ways in which each category of scaffolding within the framework might be realized.

Introduction
The need for a supportive dimension in learning and teaching has long been recognized (Biggs, 1999), but many educators claiming to espouse a discovery learning approach tend to overlook the need to provide students with adequate and appropriate structure and scaffolding. Mayer (2004) has cautioned against such “pure discovery learning” approaches, pointing to a substantial body of evidence that demonstrates their inefficiencies and shortcomings. Similarly, Kirschner, Sweller, and Clark (2006), drawing on research on human cognitive architecture, expert–novice differences and cognitive load, criticize and highlight the problems inherent in unguided and minimally guided approaches to instruction. They argue that instructional guidance should only be reduced or removed when learners have amassed sufficient prior knowledge to permit “internal” guidance. This perspective is shared by Roblyer, Edwards, and Havriluk (1997), who maintain that discovery learning is “most successful when students have prerequisite knowledge and undergo some structured experiences” (p. 68). Many opponents of pure discovery learning advocate instead the use of guided discovery (Leutner, 1993), which brings together aspects of discovery learning and principles from cognitivist instructional design theory. Guided discovery attempts to strike a balance between learner-driven discovery and open-ended exploration on one hand, and instructor-supplied guidance and structure on the other. In doing so, it is believed to increase the likelihood of deep learning occurring when compared to didactic, transmissive modes of teaching, while at the same time mitigating or avoiding the problems with pure discovery learning (de Jong & van Joolingen, 1998).

Guided discovery emphasizes the need for scaffolding, a term coined by Wood, Bruner, and Ross (1976) as a metaphor to depict a process in which an expert or other competent individual (e.g., teacher) provides support to a novice (learner) in accomplishing a task or attaining a goal. Scaffolding involves systematically providing supportive aids in the form of tools, strategies, and guides targeted to the learner’s zone of proximal development (ZPD, the gap between the learner’s current or actual development level and his/her emerging or potential level—Vygotsky, 1978), to assist progression to the next potential developmental level. Since the 1970s, a wealth of theoretical and empirical research conducted in traditional, face-to-face settings has been dedicated to the formulation of design principles, guidelines, and models for scaffolding learning. A key question is how to go about applying these to the design of technology-mediated learning environments, especially those with a discovery or guided discovery learning focus. In the next section, we propose a new framework for understanding the types of scaffolding that are possible in technology-mediated learning environments, after which we expound on the framework through illustrative examples.

Scaffolding in Technology-Mediated Environments: A New Framework
A number of attempts have been made by various researchers to classify and taxonomize the types or applications of scaffolding that may be used in technology-mediated learning environments. According to Winnips and McLoughlin (2000), for example, applications of scaffolding can be categorized according to who regulates the scaffolding (e.g., the teacher, the software, peers, the learner him/herself), the technology used, the pedagogy used, or the intended learning outcome. McLoughlin (2002) defines nine somewhat overlapping categories of learner supports or scaffolds: “orientation: communication of expectation,” “coaching,” “eliciting articulation,” “task support,” “expert regulation,” “conceptual scaffolding,” “metacognitive scaffolding,” “procedural scaffolding,” and “strategic scaffolding.” A shortcoming of this categorization is that some of the categories represent the type of knowledge development that is being scaffolded (e.g., conceptual scaffolding, procedural scaffolding), while others represent the way in which the scaffolding is provided (e.g., coaching, task support). To address this shortcoming, we have devised a two-dimensional framework, with the first dimension being the type of knowledge development intended to be supported, and the second dimension being the way in
which the scaffolding is provided, that is, the overarching pedagogical technique used. The knowledge dimension consists of three categories—procedural, conceptual, metacognitive—and the pedagogical dimension consists also of three categories—instruction, coaching, and the provision of supporting/enabling tools.

**The Knowledge Dimension**

The categories in our knowledge dimension draw on the definitions of knowledge types in the revised version of Bloom’s Taxonomy proposed by Anderson and Krathwohl (2001). Each of the three categories in this dimension is described in turn below.

*Procedural scaffolding.* An important element of constructivist learning theory is the idea that learners should be given the opportunity to carry out realistic tasks, with the assistance of scaffolding to enable them to complete the larger task without needing to learn all of the subsidiary or sub-tasks involved (Bruner, 1986). Ideally, as a by-product of such procedural scaffolding, the learner will learn how to complete the sub-tasks so that eventually he/she will be able to carry out the larger task unassisted. This type of scaffolding corresponds to Anderson and Krathwohl’s (2001) procedural knowledge category, which they consider to be knowledge of “how to do something” (p. 214). This comprises knowledge of subject-specific skills and algorithms, knowledge of subject-specific techniques and methods, as well as knowledge of the criteria to use to determine when to use the appropriate skills, algorithms, techniques, and methods. Applied to technology-mediated learning environments, procedural scaffolding focuses on suggesting various ways to leverage the available resources and tools within the environment to achieve a desired outcome.

*Conceptual scaffolding.* Conceptual knowledge entails an understanding of how basic factual elements are interlinked to form a larger pattern or structure. Conceptual knowledge includes knowledge of classifications and categories, knowledge of principles and generalizations, and knowledge of theories, models, and structures (Anderson & Krathwohl, 2001). Conceptual scaffolding therefore involves the provision of support to assist the learner in assimilating or constructing internal representations of these knowledge structures within the subject or problem domain at hand.

*Metacognitive scaffolding.* Metacognitive knowledge is knowledge about cognition in general as well as awareness of and knowledge about one’s own cognitive abilities and processes (Anderson & Krathwohl, 2001). Metacognition is a key element of self-directed and self-regulated learning (Biggs, 1987; Zimmerman & Schunk, 1989; Boekaerts, Pintrich, & Zeidner, 2000), and hence has especially important implications for the design of learning tasks and environments that seek to afford a high level of learner autonomy and control. Metacognitive scaffolding is support for the learner as he/she manages and monitors his/her own learning, which includes setting learning goals, formulating and selecting cognitive strategies, regulating learning processes, and engaging in reflection on both the processes and the outcomes.

In addition to procedural, cognitive, and metacognitive knowledge, Anderson and Krathwohl (2001) identify a fourth knowledge category, factual knowledge, which we consider to be less relevant to the present discussion on scaffolded discovery learning. This is because it is arguable that the learning of factual knowledge through discovery learning methods does not really require scaffolding in the way the learning of procedural, conceptual, and metacognitive knowledge does. Although scaffolds may be implemented that point or direct learners to materials or resources aimed at developing their basic factual knowledge, our contention is that suggesting resources in this way is a means of supporting the learner in regulating his/her own learning strategy, and as such is more appropriately classed as a form of metacognitive scaffolding.

**The Pedagogical Dimension**

The second dimension of our scaffolding framework, the pedagogical dimension, categorizes the ways in which scaffolding can be provided in technology-mediated learning environments. The three categories in this dimension are explained below. In arriving at these categories we examined the various techniques implied by categories used in earlier frameworks, such as that proposed by McLoughlin (2002), and attempted to identify the conceptually distinct pedagogical techniques encompassed within them.

*Instruction.* This is the provision of support for the learner through lectures, demonstrations, or the modeling of ideal or expert behaviors. It normally occurs prior to the commencement of a learning task or activity (known as front-loaded instruction), although instances of back-loaded instruction exist, for example in the form of summaries or reminders about key points following the completion of an activity.

*Coaching.* This involves the provision of support for the learner during learning tasks. Such support is normally reactive in that it is delivered to address identified misconceptions or gaps in the learner’s knowledge or understanding. It is also adaptive in that each learner is provided with coaching that is individualized to suit his/her specific needs as distinct from those of other learners and changed as needed over the course of a particular task.

*Tools.* Not all forms of scaffolding entail intervention by an external agent. Scaffolding can also be achieved through making available supporting tools that the learner is able to invoke when necessary, choosing when, where, and how to use these to support his/her learning. (Here, “tools” refers to both discrete software
objects or functions within the application or environment as well as features or attributes of the overall environment.) Such tools enable the learner to undertake given tasks or support the performance of those tasks by making certain aspects of the tasks easier. They include tools that help with procedural tasks, tools that help with understanding concepts, and tools that help the learner to perform metacognitive functions. Metacognitive scaffolding, for example, can be provided by supplying a cognitive tool (Jonassen, 1994) such as an electronic notepad or a concept-mapping tool and encouraging learners to use it to record their thinking and articulate/externalize their mental models.

**Examples Illustrating the Framework**

As Table 1 shows, the three techniques that comprise the pedagogical dimension of our framework can each be used to target the three types of knowledge development, yielding nine distinct types of scaffolding in total that are possible within a technology-mediated learning environment. General examples of the categories produced by the intersections of the pedagogical techniques and knowledge types are contained within the nine corresponding cells of the table. More specific, detailed examples from various disciplines that are representative of the categories are included in the ensuing subsections.

> Table 1. Dimensions of scaffolding in technology-mediated learning environments

<table>
<thead>
<tr>
<th>KNOWLEDGE Dimension</th>
<th>PEDAGOGICAL Dimension</th>
<th>Tools</th>
</tr>
</thead>
<tbody>
<tr>
<td>Procedural</td>
<td>Instruction</td>
<td>Coaching</td>
</tr>
<tr>
<td>Example: Presentation of a recommended sequence of steps to carry out an overall learning task, as part of an orientation or briefing preceding the task</td>
<td>Example: Advice about how to navigate through a part of the environment (i.e., when the learner has become stuck)</td>
<td>Example: Provision of a tool that allows the learner to bookmark a page or location for later viewing</td>
</tr>
<tr>
<td>Conceptual</td>
<td>Example: A video lecture on a particular theoretical concept in the learning domain</td>
<td>Example: Alternative explanation of a concept, delivered in response to the learner’s unsuccessful attempt to carry out a task</td>
</tr>
<tr>
<td>Metacognitive</td>
<td>Example: Suggestion of a number of possible learning tasks that the learner could undertake to further develop or reinforce his/her understanding</td>
<td>Example: Rhetorical or leading questions in the form of prompts asked of the learner to help him/her solve a problem</td>
</tr>
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</table>

**Procedural Instruction**

Procedural instruction is instruction about the steps involved in a particular procedure, which may either be an overall task to be undertaken or a subsidiary task (sub-task) that forms part of the larger, overall task. For example, an accounting student could be provided with a list of the steps involved in developing an annual budget for a small business, presented as a set of clickable hyperlinks that take him/her to a more detailed explanation of each step. Moreover, a digital video could be provided in which an explanation of the key aspects of the task are presented. Screencasts could be used to demonstrate how to perform various procedures in the accounting software package that is to be employed to prepare the budget. In an immersive virtual learning environment, procedural instruction may be supplied via a personified agent within the environment whose actions and speech are controlled by a simple script. For example, a virtual “teacher” appearing as an avatar within the environment might model the correct procedure for operating a piece of equipment or machinery.

**Procedural Coaching**

Procedural coaching is similar to procedural instruction except that it is provided in response to some action (or lack thereof) performed by the learner, perhaps illustrating deficiencies or gaps in knowledge of a specific procedure. The simplest form of such coaching would be demonstrations of procedures provided as an option when it is detected that the learner is attempting a particular procedure. An example of this can be seen in the case of a veterinary science student undertaking a problem-based learning activity calling for the diagnosis of the condition suffered by a simulated animal. Here, the student could be provided with suggestions about particular examination procedures or tests to be done on the animal, along with the option to view multimedia content relating to those procedures.

Rather than being completely dynamic, procedural coaching could consist of a scripted animation performed by an agent, a pre-recorded audio-visual presentation or a series of text messages displayed to the learner, in a similar way to procedural instruction. The provision of such “pre-fabricated” or scripted support could be implemented using a set of relatively simple rules or triggers, specifying which animations, videos, recorded audio or text messages to activate in response to which learner actions. For example, in the veterinary science activity, the choice of what suggestions to provide to the learner could be determined through simple...
conditional or branching logic that detects whether the learner has completed certain identified milestones within the procedure. The suggestions could be delivered proactively by the system or in response to a request from the learner (e.g., by clicking on a button/menu item labeled Help... or Hints...).

**Procedural Tools**
Many general-purpose tools commonly found in technology-mediated learning environments, such as calculators, graph generators, and spell checkers, can be considered instances of procedural tools. An example of a more specialized procedural tool is a template given to a teacher education student to simplify the process of designing a lesson; another is an applet made available to a nutrition student within a web-based scenario learning environment that he/she can use to help calculate the fat, sugar, and carbohydrate content of a particular meal when attempting to plan a diet for a patient.

**Conceptual Instruction**
Conceptual instruction is instruction to help learners understand the concepts involved in a task that they are either about to undertake or have just completed. As with procedural instruction, this type of instruction could be provided as video, audio, or text material displayed on screen to the learner, or as scripted animations carried out by a personified agent. For example, a biology student could be provided with an animation illustrating the concept of photosynthesis with an audio track explaining the key aspects.

**Conceptual Coaching**
Conceptual coaching differs from conceptual instruction in that it occurs as a result of an action carried out by the learner implying he/she is in need of assistance or guidance in relation to a conceptual aspect of his/her current task. If conceptual coaching is to be provided by the system—as distinct from a real tutor present within a multi-user virtual environment, for example—then complex inferences about the learners’ cognitive learning processes are required. That is, unlike procedural coaching, which may be provided by the system in response to an unsuccessful attempt at a procedure by the learner, system-provided conceptual coaching requires the software to make assumptions about the cognitive aspects of the current task and about possible misconceptions indicated by learners’ behaviors or actions.

As an example of conceptual coaching, an oncology student using virtual microscopy to analyze images of cancer cells might be provided with an animation with an instructional audio track explaining the key indicators of certain cell abnormalities. This might occur as a result of the learner specifying an incorrect classification or diagnosis, or it could occur simply as a result of the learner clicking on Help... or Hints... .

**Conceptual Tools**
Conceptual tools are tools that help the learner to understand the concepts involved in a task they are undertaking or in an aspect of the environment they are exploring. These tools can, for instance, be visualization tools that allow the learner to observe aspects of the environment not normally visible to the naked eye. They can also be interactive components of the virtual environment that the learner can use to “magically” carry out a task to help them to understand a particular concept. For example, a chemistry student undertaking an experiment in a virtual laboratory could be provided with a tool that allows him/her to zoom in to the molecular level to observe a simulation of the molecular structures occurring as a result of the reaction.

Some tools that make certain procedures quicker or more efficient may also be considered conceptual tools because they actually scaffold the concepts to be encountered through the task. For example, in a simulated chemistry laboratory, a tool that dynamically calculates and displays the ratio of one solution to another during a titration experiment may help the learner understand the chemistry involved more effectively than in the traditional approach, where he/she must calculate the ratios upon completion of the experiment.

**Metacognitive Instruction**
Metacognitive instruction may consist of instruction about the “big picture” or high-level tasks that the learner should undertake within the environment in order to optimize or enhance his/her learning. Mayer (2004) cites the absence of this initial orientation as being one of the key reasons for the failure of pure discovery learning. For example, a student of political science could be provided with a series of focus questions to answer as he/she reads a newspaper article, parliamentary report, or other archival document, to help him/her identify some of the less obvious aspects of the written work. An additional element of such introductory instruction could be the suggestion of self-regulatory and reflective strategies.

**Metacognitive Coaching**
Metacognitive coaching is coaching to encourage and facilitate metacognitive tasks such as goal setting, formulation and selection of cognitive strategies, self-regulation and management of learning processes, and reflection. Providing opportunities for articulation may be beneficial because it not only highlights and draws
the learner’s attention to specific concepts in the context of the task being performed, but also promotes deep learning by encouraging the learner to be aware of and consciously reflect on his/her evolving understanding of those concepts. For example, a social work student trying to identify the appropriate intervention in a domestic situation based on reading a set of case notes could be provided with a series of questions such as “What are the key aspects of the case that need to be considered?” or “What legal and regulatory requirements are applicable here?” Such questions would encourage the student to focus on the important aspects of the case and important elements of his/her own prior knowledge while undertaking the analysis.

Like conceptual coaching, programmatically implementing metacognitive coaching within a technology-mediated learning environment is not straightforward, due to the need to deduce the cognitive needs of the learner at a particular point in time. Again, an alternative is to provide a list of metacognitive support options potentially relevant to the current task, and have the learner choose the support needed and/or desired.

**Metacognitive Tools**

Metacognitive tools are tools aimed at helping the learner to undertake metacognitive tasks such as goal setting, self-regulation, and reflection. As an example, a clinical psychology student attempting to diagnose the disorder suffered by a hypothetical patient after reading the transcript of a series of sessions with a psychologist could be provided with a tool allowing him/her to embed comments in the text, coded with different colors for patient history, patient relationships, and patient attitudes.

**Conclusion**

In this paper, we have proposed a new framework for classifying and understanding the types of learning scaffolds possible in technology-mediated environments. The first dimension of the framework relates to the knowledge development intended to be supported, while the second characterizes the pedagogical technique or way in which the scaffolding is provided. This results in a total of nine scaffolding types, each of which has been illustrated and typified in the paper by means of examples. Future work is needed that assesses the appropriateness and completeness of the proposed framework. This can be accomplished through analyses of scaffolding examples from the literature together with empirical studies exploring the characteristics of scaffolding provided by teachers within both face-to-face and online learning environments. Beyond that, research is needed to ascertain precisely which scaffolding types are most appropriate in different technology-mediated learning situations and scenarios, and to test their efficacy in supporting different types of learning goals and outcomes within various subject disciplines and domains.

**References**


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