Suggest-Assert-Modify: A Taxonomy of Adaptive Scaffolds in Computer-Based Learning Environments

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Abstract. Adaptive scaffolding in computer-based learning environments (CBLEs) continues to be an active area of research, with researchers framing the problem as determining the *what*, *when*, *how*, and *by whom or what* of adaptive scaffolding strategies. This paper presents our recent work in developing a taxonomy for adaptive scaffolds in CBLEs. The taxonomy, motivated by previous work in developing adaptive scaffolds, attempts to address the *how* of scaffolding by describing the tools and techniques available for scaffolding in CBLEs. We present the taxonomy, which describes adaptive scaffolds as one or more suggestions, assertions, and learning task modifications, and we discuss the utility of the taxonomy in describing adaptive scaffolding strategies.

Keywords: adaptive scaffolds, taxonomy, computer-based learning environments

1 Introduction

Research in computer-based learning environments (CBLEs) has long recognized the vital role of adaptivity in the success of a system's ability to independently foster learning in students [1]. Adaptive CBLEs regularly capture and analyze student activities in order to make decisions about how and when to scaffold learners [2]. These systems *take explicit actions* [3]; they may remind learners of relevant information, advise learners on how to proceed in their learning tasks, or modify the difficulty level of the learning activity itself.

The methods and tools used for scaffolding may vary widely based on the goal of instruction. For example, Chi and colleagues [4] presented 15 types of scaffolding actions identified in the research literature. These scaffolds include providing hints, fill-in-the-blank prompts, explanations, and correct answers, among others. Understanding these techniques, including when and why a particular scaffold may be more effective than another, remains an important area of research. Pea [5] framed the problem as defining the *what*, *why*, and *how* of scaffolding. *What* information should a scaffolding action focus on, w*hy* should a CBLE employ a scaffold, and *how* does the CBLE actually scaffold the learner (*i.e.*, what action does it take)? This framework was later revised by Azevedo & Jacobson [2] to focus on *what*, *when*, *how*, and *by whom or what*. The revised framework replaces the *why* question with a *when* question: *when* should a CBLE scaffold learners? It also introduces a new question: who or what should provide the scaffolds?

In this paper, we attempt to address the *how* question by presenting a novel taxonomy for classifying adaptive scaffolds in CBLEs. The taxonomy classifies adaptive scaffolds as a set of one or more *suggestions*, *assertions*, and learning task *modifications* (SAMs). Section 2 presents the background and motivation for the taxonomy; section 3 presents the taxonomy; and section 4 discusses future directions.

2 Previous Work in Classifying Adaptive Scaffolds

While some researchers in the field of educational technology have proposed methods for classifying and describing adaptive scaffolding approaches based on well-defined terms (*e.g.*, [6-7]), no comprehensive taxonomy of the tools and techniques available for scaffolding currently exists. Thus, the field now suffers from a lack of operational definitions, and several researchers refer to the scaffolds in their systems as “hints” or “feedback.” Often, researchers define these scaffolds via examples. Bell & Davis [8], for instance, differentiate between three types of hints provided by a pedagogical agent named Mildred: activity hints, evidence hints, and claim hints. The provided descriptions of the hints are vague, and they are mainly illustrated with examples:

> The current instantiation of Mildred provides three types of hints - on activities, evidence, and claims. For example, in the “Critique Evidence” activity of All The News, an activity hint might say, “When you critique the evidence, you will think about: (1) the science ideas used in the evidence, (2) the methods used to create the evidence, and (3) how credible or believable the evidence is.” Further activity hints for the Critique Evidence activity would provide definitions and examples of the critique criteria of science, methods, and credibility. Evidence hints are more specific, providing help in thinking about a particular piece of evidence. A hint for the “Bicyclists at Night” evidence (used in both All The News and How Far) is, “Why is the person in white [clothes] easier to see? What is happening to the light?” A student working on a critique of the Bicyclists at Night evidence could then receive converging evidence on both the act of critiquing and the specific evidence being critiqued. Likewise, claim hints help students think about a particular claim. For example, a claim hint about black “attracting heat” (as opposed to absorbing light) might say, “What would happen if there were a heat source in a dark room? Would someone wearing black get hotter than someone wearing white?” (p. 144)

Similarly, Jackson, Guess, & McNamara [9] present a CBLE, *iStart*, and describe the scaffolds provided by the system as “feedback” without defining the term, instead relying on examples:

> Merlin provides feedback for each explanation generated by the student. For example, he may prompt them to expand the explanation, ask the students to incorporate more information, or suggest that they link the explanation back to other parts of the text. Merlin sometimes takes the practice one step further and has students identify which strategies they used and where they were used. (p. 129)

Some researchers have developed more specific scaffold classifications. For example, Belland, Glazewski, & Richardson [10] propose four types of scaffolds: conceptual support, metacognitive support, procedural support, and strategic support. These support types are defined as help about "what to consider," "how to manage the learning process," "how to use tools," and "what strategies to use in approaching the problem," respectively. This classification differentiates scaffolds based on a single dimension: the type of information the scaffold is designed to support. However, because scaffolds are *actions*, an appropriate classification needs to consider both what information is supported and how it is supported.

In presenting a general framework for the design of Intelligent Tutoring Systems (ITSs), VanLehn [6] defines minimal feedback and three types of hints: point, teach, and bottom out. In ITSs, learners are presented with small multi-step problems in a well-defined domain (*e.g.*, physics). When students are having trouble correctly completing a problem step, the system usually intervenes to provide one of these types of scaffolds. Minimal feedback scaffolds indicate whether or not a learner's attempt at completing a problem step is correct or incorrect. Hints are provided in relation to a particular knowledge component (*e.g.*, a fact, definition, or procedure), and they are defined as follows:

> Pointing hints mention problem conditions that should remind the student of the knowledge component's relevance. Teaching hints describe the knowledge component briefly and show how to apply it. Bottom-out hints tell the student [how to apply the knowledge component to solve] the [current problem] step. (p. 242)

This scaffold classification, unlike the classification described in [10], does focus both on the information the scaffold is designed to support and the methods by which the information is supported. However, it is not general enough to classify a number of scaffolds that have been implemented in CBLEs. For example, several CBLEs provide scaffolds that suggest the use of a particular resource within the system rather than mentioning or explaining a knowledge component.

As a final example, Graesser & McNamara [7] describe the scaffolds implemented within a CBLE called *AutoTutor*, which teaches physics by posing questions and then holding natural language dialogues with learners as they attempt to answer those questions. During the course of these dialogues, *AutoTutor* may employ any of five types of dialogue moves: pumps, hints, prompts, correctness feedback, and assertions. *Pumps* ask the learner to continue elaborating on the answer they have started to offer. For example, *AutoTutor* might encourage a student to “keep going.” *Hints* are questions that attempt to elicit a question-relevant proposition from the learner. For example, *AutoTutor* may ask students how Newton’s second law of motion applies to the current question. *Prompts* are questions that ask the learner to provide explicit words or phrases that are important in answering the current question. For example, *AutoTutor* may present a partial definition of Newton’s second law of motion and ask the learner to fill in the missing information. *Feedback* indicates whether the learner’s answer is correct or incorrect, and *assertions* communicate entire propositions to learners when hints and prompts fail to elicit them.

In considering the presented scaffold classifications, some common themes emerge. First, several of the presented scaffolds operate by *providing a suggestion*. For example, pointing hints in ITSs direct attention to specific problem features, suggesting that learners consider those features; Merlin suggests that learners link their current explanation back to other parts of the text; and *AutoTutor* pumps learners, suggesting that they continue elaborating on their answer. Second, several of the presented scaffolds operate by *asserting information*. For example, teaching hints assert knowledge components and how to apply them; bottom-out hints assert how to solve the current problem step; and *AutoTutor’s* assertions communicate question-relevant propositions to learners. Third, some scaffolds operate by *modifying the learning task*. For example, when *AutoTutor* asks the learner a question as part of delivering a hint, it is redirecting the learner’s attention away from their former task (answering the original question) to a new task (answering a related question).

These observations have led us to develop a taxonomy that classifies adaptive scaffolds as one or more suggestions, assertions, and learning task modifications. This taxonomy is general and widely-applicable. Moreover, it provides a language for presenting and communicating scaffolding strategies.

3 The Suggest-Assert-Modify Taxonomy

The Suggest-Assert-Modify (SAM) taxonomy is illustrated in Figure 1. Suggestion scaffolds provide information to learners for the purpose of prompting them to engage in a specific behavior (*e.g.*, accessing a resource). By executing the recommended behavior, learners should encounter critical information that, if properly internalized, would allow them to make progress in accomplishing the learning task. The taxonomy classifies suggestions based on whether they target metacognitive activities (*e.g.*, planning or reflection) or cognitive knowledge integration activities. Knowledge integration is the process of analyzing and connecting multiple chunks of information in order to achieve new understandings about how they are related [11-12]. It can target several cognitive processes, such as: (i) goal orientation, in which learners integrate chunks of information with their understanding of their current goal; (ii) explanation construction, in which learners assemble chunks of information to explain a system, process, or phenomenon; (iii) prediction, in which learners integrate chunks of information with a hypothetical scenario, and several others.

Assertion scaffolds communicate information to learners as being true; ideally, learners will integrate this information with their current understanding as they continue working toward completing their learning task. Unlike suggestions, assertion scaffolds don't directly encourage learners to engage in a particular behavior; they only state information.

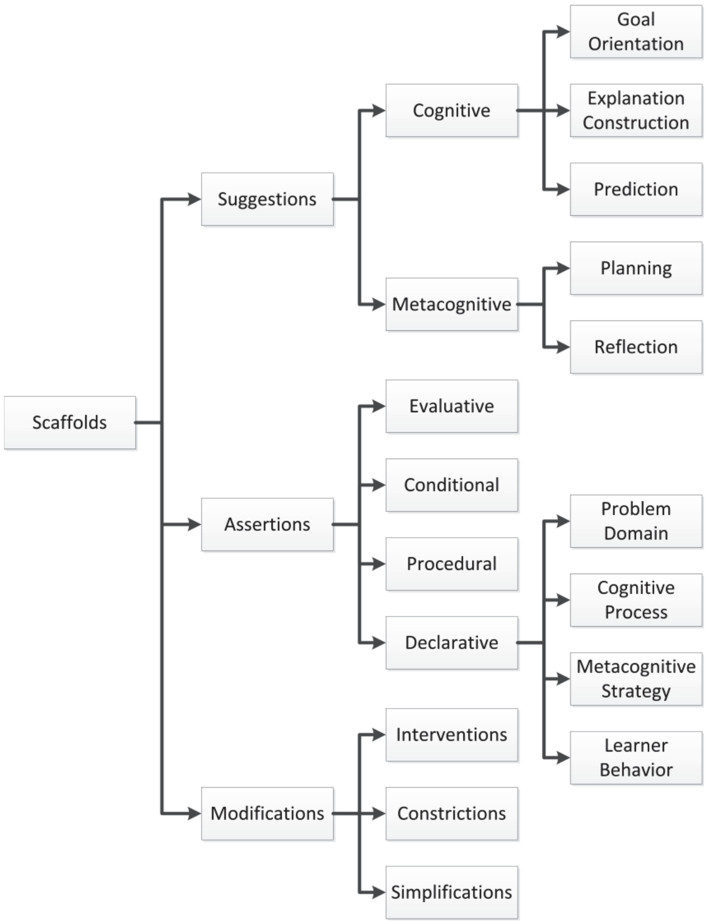

Fig. 1. The SAM Taxonomy for Adaptive Scaffolds

The taxonomy distinguishes between four types of assertion scaffolds: declarative, procedural, conditional, and evaluative. Declarative assertions communicate "knowing that" information [11]. Such information is often conceptualized as being represented as and with schemata: mental structures that represent a concept and the features that characterize it [12]. For example, a schema representing an animal might contain features such as the animal's number of legs and the sound that the animal makes. Features correspond to variables in an algebra expression or computer program; they can take on any of a number of values when instantiated; and an "instance" of an animal schema may represent an actual animal in the world. Thus, declarative assertions contain information that may be represented by a schema; this includes facts, definitions, concepts, and understandings of relationships and interrelationships among actors in complex systems. In the proposed taxonomy, declarative assertions are sub-divided based on their topic, which may be the problem domain, cognitive processes, metacognitive strategies, and the learner's behavior while using the system. Examples of each type of declarative assertion are listed in Table 1.

Assertion Category	Example
Declarative – Problem Domain	Sunfish eat mosquito fish.
Declarative – Cognitive Processes	You have to know how to multiply fractions.
Declarative – Metacognitive Strategies	The "cross-multiply" strategy may help you.
Declarative – Learner Behavior	You haven't tried any division problems.
Procedural	To multiply fractions, first multiply the numerators, and then multiply the denominators.
Conditional	The "cross-multiply" strategy should be used whenever you need to solve for an unknown value in an equation consisting of only fractions.
Evaluative	You don't seem to have a good understanding of how to divide fractions.

Table 1. Types of Assertion Scaffolds with Examples.

Procedural assertions communicate "how-to" information: sets of actions that, when executed in a loosely-ordered sequence, can accomplish a task. These assertions explain how to perform cognitive processes, such as identifying important information in text passages or applying causal reasoning to answer hypothetical questions. Conditional assertions communicate information represented as "if-then" rules that identify both when cognitive processes are applicable and whether or not they should be executed based on the current context [12]. These assertions usually explain metacognitive strategies. In a fractions learning environment, for example, the system might assert that a good strategy for solving algebraic expressions that consist entirely of fractions is to use a "cross-multiply" strategy. This would be represented as the following "if-then" rule: *IF you want to solve an algebraic expression consisting entirely of fractions, THEN employ the cross-multiply strategy*. Finally, evaluative assertions communicate evaluations of the learner's performance and understanding. For example, the system may assert that the learner does not seem to understand how to divide fractions.

Modification scaffolds, unlike suggestion and assertion scaffolds, do not operate by communicating information to the learner; rather, they change aspects of the learning task itself. In doing so, they seek to adapt the task to the learner's needs and abilities. The taxonomy differentiates between three types of modification scaffolds: simplifications, constrictions, and interventions. Simplification modifications, as specified by Wood, Bruner, & Ross [13], operate by "reducing the number of constituent acts required to reach solution." Constriction modifications operate by reducing the number of options available to the learner. For example, the scaffolding agent may block access to tools or resources in order to focus learners' attention on other, more useful approaches to solving the task. Intervention scaffolds, rather than modifying features of the overall task, operate by temporarily shifting learners' attention from their primary task to an intervention task. Upon completion of the intervention task, learners may return to the primary task.

The SAM taxonomy addresses the *how* of scaffolding by describing the atomic elements of adaptive scaffolds, and it provides a language for communicating both individual scaffolds and entire scaffolding strategies. For example, the scaffolding strategy for ITSs discussed by VanLehn [6] could be described as a progression from cognitive suggestions (pointing hints) to declarative assertions that describe a knowledge component (teaching hints) to declarative assertions that provide the answer to the current problem step (bottom-out hints). In comparison to the scaffolding classifications presented in Section 2, we argue that the SAM taxonomy is more comprehensive and general than its predecessors.

4 Conclusion

This paper has presented a novel taxonomy for describing and classifying adaptive scaffolds in computer-based learning environments. The taxonomy classifies adaptive scaffolds as one or more suggestions, assertions, and learning task modifications, and it provides a general, widely-applicable language for communicating and interpreting scaffolding strategies.

The SAM taxonomy, however, is not without limitations. First, the distinction between suggestions and assertions is sometimes ambiguous, and a scaffold may consist of an assertion that implies a suggestion. For example, a scaffold in an algebra learning environment may assert that successful students used a particular problem solving strategy in order to indirectly suggest that the learner adopt that strategy. Second, the SAM taxonomy does not currently distinguish between different types of intervention scaffolds. Future work should investigate methods for breaking down interventions according to the types of activities learners are expected to accomplish during the intervention. For example, it may be valuable to separate modeling interventions (*e.g.*, demonstrating how to solve a problem), metacognitive interventions (*e.g.*, requiring learners to gauge their own comprehension), and cognitive interventions (*e.g.*, requiring learners to correctly define terms or explain properties of a complex system).

It is important to note that the presented taxonomy represents an initial step toward a standardized language for describing the *how* of adaptive scaffolding strategies. As we continue to scan the literature for more examples of adaptive scaffolds in educational technology, we will update the taxonomy as needed to reflect distinguishing features of adaptive scaffolds.

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