Scaffolding Higher-Order Thinking during Ill-structured Problem Solving: A Conceptual Framework

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Abstract

Novice and expert problem solvers use different strategies in approaching ill-structured problems, indicating lower-order and higher-order thinking skills respectively. There is a need to guide novices to use better problem-solving strategies through developing their higher-order thinking skills. According to theory and research, analytic, generative, and evaluative thinking skills are essential to successful ill-structured problem solving performance. We propose a framework designed to promote higher-order thinking skills during ill-structured problem-solving. Scaffolding features, types, and functions of an open-ended learning environment can be used as guidelines for creating scaffolds to facilitate the novices' acquisition and utilization of the three fundamental thinking skills. Possible ways of scaffolding novice problem solvers to use higher-order thinking skills are discussed based on the scaffolding design in various ill-structured learning domains.

Problem Area

The real-world problems confronting practitioners are usually saturated with “complexity, uncertainty, instability, uniqueness, and value conflict” and require the practitioner to “choose among multiple approaches to practice or devise his own way of combining them” (Schön, 1993, pp. 17-18). Cognitive psychologists define these problems as ill-structured or ill-defined because they have unspecified problem space (e.g., elements, goals, constraints, principles, etc.), divergent perspectives, multiple solutions, and unclear evaluation criteria, entailing a dialectic and iterative problem-solving process (Chi & Glaser, 1985; Kitchner, 1983; Sinnott, 1989; Voss & Post, 1989). From constructivism and situated cognition perspectives, educational researchers (e.g., Bransford, Brown, & Cocking, 2000; Bransford & Stein, 1993; Jonassen, 1997) emphasize the importance of engaging students in ill-structured problem solving in order to situate learning in authentic tasks and to develop transferable knowledge and skills.

Ill-structured problem solving is difficult for novices with deficiencies in the prerequisites of this activity. Literature show that the major predictors of ill-structured problem-solving performance include: 1) domain knowledge (e.g., Chi & Glaser, 1985; Diakidoy, 2001; Shin, Jonassen, & McGee, 2003), 2) dispositions and beliefs (e.g., Mumford, Baughman, Threlfall, & Uhman, 1993; Schraw, Dunkle, & Bendixen 1995), 3) higher-order thinking skills (e.g., Lee & Cho, 2007; Mumford, Baughman, & Threlfall et al., 1996, 1997; Schunn, McGregor, & Saner, 2005; Shin et al., 2003), and 4) metacognition (e.g., Brown, 1987; Lin, 2001; Sinnott, 1989). Novices do not possess extensive and well-organized knowledge framework for problem solving. Many of them develop simple epistemological beliefs about the problem domain and take close-minded attitudes toward new ideas. As a result, they tend to apply a single schema to ill-structured problem solving in order to situate learning in authentic tasks and to develop transferable knowledge and skills.

To address these challenges, more and more educational researchers have realized the need to provide external instructional support to facilitate cognitive and metacognitive processes during ill-structured problem solving. A variety of scaffolds have been implemented to support the aforementioned four predictors by facilitating knowledge integration (e.g., Chen & Bradshaw, 2007; Davis & Linn, 2000), argumentation and justification (e.g., Cho & Jonassen, 2002; Oh & Jonassen, 2007), exploration of alternative ideas or perspectives (e.g., Choi & Lee, 2009; Uribe, Klein, & Sullivan, 2003), and metacognitive regulation of the problem-solving process (e.g., Ge & Land, 2003; Wolf, Brush, & Saye, 2003). According to the findings, although learners’ ill-structured problem-solving skills were enhanced to some extent, new challenges emerged as the scaffolding effects were unsatisfactory. For example, learners tended to use the scaffolds superficially and mindlessly; not all learners can benefit from the same scaffolds; multiple types of scaffolds increased cognitive load. This paper aims to develop a theoretical framework to address the original and emerging challenges in the area of scaffolding novices to solve ill-structured problems, with a focus on three particular issues.
First, novices have difficulty applying higher-order thinking skills to ill-structured problem solving. They tend to analyze the complex problems in simplified ways, overlooking the multiple factors and representations (Carrithers, Ling, & Bean, 2008; Powell & Willemain, 2007; Prietual & March, 1991). Moreover, they focus on the fragmented details instead of the meanings and relationships and have difficulty distinguishing the relevant from the irrelevant information (Powell & Willemain, 2007). In generating solutions, novices usually fail to consider alternative ideas and perspectives (Osana, Tucker, & Bennett, 2003; Prietual & March, 1991) or lose their focus in discursive exploration of ideas (Kapur, 2008; Powell & Willemain, 2007). They are likely to build solutions based on available salient information rather than consult and integrate additional resources. Also, it is difficult for novices to determine good criteria for evaluating the solutions and developing strong arguments. They tend to make rapid, uninformed decisions, which in turn cut short their search for alternatives (Osana et al., 2003; Schunn et al., 2005). Studies showed that higher-order thinking skills, which are supported by the other predicting factors mentioned earlier, have significant influence over ill-structured problem-solving performance (Lee & Cho, 2007; Mumford et al., 1996, 1997; Schun et al., 2005; Shin et al., 2003). Inadequate higher-order thinking skills will inevitably limit the solver’s cognitive capacities of processing the ill-structured problems.

Second, learners tend to misunderstand, misuse, or ignore the scaffolds and their functions, reducing the scaffolding effectiveness. Frequently, learners fail to reflect on the purposes and strategic functions of the scaffolds and rarely go beyond answering questions to seek further understanding (e.g., Oliver & Hannafin, 2000). They are inclined to use lower-order thinking skills in responding to the scaffolds or simply ignore the opportunities of higher-order thinking (e.g., Davis & Linn, 2000; Land & Zembal-Saul, 2003). They try to solve problems with their presuppositions rather than follow the scaffolds to critically reflect on their own and others’ perspectives (e.g., Choi & Lee, 2009; Ge, Chen, & Davis, 2005). Faced with confusions or difficulties, they easily give up using the scaffolds that demand mental efforts, especially when they experience cognitive overload (e.g., Ge et al., 2005; Greene & Land, 2000). These problems are partly due to the learners’ lack of prior knowledge, simple epistemological beliefs, and limited higher-order thinking and metacognitive skills. Additionally, the design of the scaffolds may also be responsible. Scaffolds that cannot be easily understood by the learners or fail to support their zones of proximal development are not likely to achieve the intended effects.

Third, despite the positive findings from experimental studies, the learners' skills developed under scaffolding may not be robust enough to support problem solving in new contexts. Many studies examined scaffolding effectiveness based on the comparison between experimental and control groups (e.g., Cho & Jonassen, 2002; Davis & Linn, 2000; Ge & Land, 2003; Manlove, Lazonder, & de Jong, 2007; Oh & Jonassen, 2007). Criteria for assessing problem-solving performance were aligned with the scaffolded skills and processes. They gave the experimental group strong advantages that may have confounded the conclusion that the scaffolds will significantly improve ill-structured problem-solving performance. Moreover, since most studies did not fade the scaffolds, there was little evidence that the improved performance had been internalized by the learners and could be transferred to new situations. A few studies that did fade the scaffolds found partial or even no improvement, which might be explained by the limited period of intervention (Choi & Lee, 2009) and inconsistencies between scaffolded skills and overall problem-solving performance (Cho & Jonassen, 2002; Oh & Jonassen, 2007).

According to the three issues, scaffolding ill-structured problem solving is a pressing yet challenging task, particularly in promoting the novices to use higher-order thinking skills, which are vital for professional development but difficult to obtain without facilitations. Nevertheless, as external supports, scaffolding may not always be effective and can easily lead to lower-order thinking when their functions are not recognized or utilized by the learners. Even though progress in learners’ higher-order thinking and problem-solving skills was evidenced by previous studies, it may only occur under certain conditions and cannot be sustained or guaranteed. These issues should be addressed before learners can truly benefit from and gain control over ill-structured problem-solving activities.

Theoretical Framework

To support the design and investigation of scaffolding for ill-structured problem solving, a theoretical framework should be developed to guide the inquiry. Since improving higher-order thinking skills is a critical issue, this framework aims at clarifying the specific higher-order thinking skills involved in ill-structured problem solving and adapting the scaffolding features, types, and functions to promote those skills (see Figure 1).
Higher-Order Thinking

The idea of higher-order thinking skills has no clear definition; it has, however, functioned as an important reminder that there are more advanced thinking skills that learners should develop beyond the basic cognitive skills such as remembering, comprehension, and application (Bloom, 1956; Ennis, 1987). Among the literature on higher-order thinking skills, four sources of seminal works stand out, including Dewey’s reflective thinking (1933), Bloom’s taxonomy of educational objectives (1956), Guilford’s structure-of-intellect model (1967), and Ennis’s critical thinking (1987). These theories and their further development identified specific higher-order thinking skills from different perspectives and converged on the point that higher-order thinking skills are integral to problem-solving skills. Dewey (1933) stressed the idea of problem solving in reflective thinking by highlighting “a state of doubt” and “an act of inquiry to resolve the doubt” (p.12). The three higher-order objectives in Bloom’s taxonomy (1956) – analysis, synthesis, and evaluation – are the essential components of what he called “intellectual abilities and skills” and “problem-solving skills” (p. 39). In Guilford’s structure-of-intellect model (1967), the three higher-order operations – divergent production, convergent production, and evaluation – provided theoretical ground for creativity which was considered as a “discovered problem-solving process” (Csikszentmihalyi & Getzels, 1971). Ennis (1987) suggested the process of problem solving, which integrated thinking into procedural steps, as one way of organizing critical thinking to decide on an action (p. 23). Although the four theories come from quite different fields, including philosophy, assessment, intelligence, and law, their shared connection with problem solving has made it possible to identify the common higher-order thinking categories and skills as listed in Table 1. Appendix A shows how this classification scheme was identified from the higher-order thinking skills described by each theory.

Figure 1. Framework of scaffolding higher-order thinking in ill-structured problem solving

Higher-Order Thinking

<table>
<thead>
<tr>
<th>Analytic Thinking</th>
<th>Generative Thinking</th>
<th>Evaluative Thinking</th>
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<td>Problem Identification</td>
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<td>Procedural Scaffolding</td>
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<td>Strategic Scaffolding</td>
<td>Hard, Fixed Scaffolds</td>
<td>Soft, Dynamic Scaffolds</td>
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Scaffolding Types and Functions
Analyzing the relationships and inexplicit structures of the elements and parts.

Table 1. Classification of higher-order thinking skills

<table>
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<tr>
<th>Analytic Thinking</th>
<th>Generative Thinking</th>
<th>Evaluative Thinking</th>
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<tbody>
<tr>
<td>Identifying relevant facts, evidence, and information.</td>
<td>Producing or creating plans, ideas, details, solutions, products, communications, etc. that are divergent and open-ended.</td>
<td>Evaluating the identified information or generated ideas based on correctness, consistencies, reliability, and credibility.</td>
</tr>
<tr>
<td>Analyzing given statements, reasons, hypotheses, conclusions etc.</td>
<td>Inducing or deducing beliefs, hypotheses, generalizations, conclusions, value judgments, etc. that are convergent and close-ended.</td>
<td>Evaluating the identified information or generated ideas based on satisfaction to ultimate goals or appropriateness to the context.</td>
</tr>
<tr>
<td>Identifying unstated reasons, ideas, statements, assumptions, etc.</td>
<td></td>
<td></td>
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<tr>
<td>Analyzing the relationships and inexplicit structures of the elements and parts.</td>
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The three major categories of higher-order thinking skills—analytic thinking, generative thinking, and evaluative thinking—are interconnected with one another and align well with the problem-solving process. First of all, analytic thinking serves as the prerequisite of generative and evaluative thinking. It builds upon lower-order skills that bring to bear appropriate principles and emphasizes the detection of elements, parts, and their connections or organizations (Bloom, 1956, p. 144). The goal is to clarify and focus on certain issues (Ennis, 1987, p. 17) and to support or justify the generation of ideas and beliefs (Dewey, 1933, p. 9). Both the purpose and function of analytic thinking are consistent with the identification of problems and the search for ideas to generate solutions.

Generative thinking is one step beyond analytic thinking and one step prior to evaluative thinking. With the information identified from analysis, it generates ideas in two different ways: divergent production and convergent production (Guilford, 1967). The former generates multiple, varied, and elaborated ideas that are integrated with individuals’ feelings and experience (Bloom, 1956, p. 169; Guilford, 1956, p. 138). It is best applied to open-ended situations that allow for multiple answers and encourage alternative ideas. The latter generates only one or very limited numbers of ideas through logic-tight inference of the given information (Ennis, 1987; Guilford, 1956). It is most appropriate for situations requiring ideas derived from rigorous reasoning based on evidence, rules, and principles. The two types of generative thinking can be applied selectively to problem construction and solution generation, depending on the situation.

Evaluative thinking assists analytic thinking to distinguish the relevant and credible sources of information and supports generative thinking to make good decisions. The relationship between generative and evaluative thinking, however, is more complicated. Evaluation criteria should be applied not only to evaluate the generated ideas but also to guide idea generation (Baer, 2003). Inappropriate use of criteria would either stifle divergent production or mislead convergent production (Cropley, 2006). Bloom (1956) emphasized the difference between internal and external criteria (p. 186). By assessing the internal correctness, consistencies, reliability, and credibility, evaluative thinking helps making critical judgments about the given information, deductions, and inductions (Ennis, 1987). Moreover, by using external criteria associated with the context and ultimate goals, evaluative thinking informs the generation and selection of appropriate information or ideas (Bloom, 1956; Dewey, 1933; Guilford, 1967). As evaluative thinking is inseparable from analytic and generative thinking, it must be essential to problem construction and solution generation as well.

Theory and research show that higher-order thinking skills, as represented by analytic, generative, and evaluative thinking, are associated with domain knowledge, dispositions, and metacognition. Domain knowledge is necessary for applying general thinking principles and provides the sources of generative thinking (Dewey, 1933; Ennis, 1987; Guilford, 1967). Studies found that in ill-structured situations, domain knowledge facilitated the thinking process of structuralizing and reasoning through the open-ended problem space (e.g., Diakidoy & Constantinou, 2001; Lee & Cho, 2007). Some advocates claimed, however, that teaching higher-order thinking skills enhances the learning of domain knowledge as well (Dewey, 1933; Walsh & Paul, 1985). Furthermore, learners should also have dispositions that encourage them to use higher-order thinking skills (Dewey, 1933; Ennis, 1987), such as being open-minded, seeking clarifications, focusing on the main point, etc. Studies found open-minded attitudes, including openness to new ideas and flexibility with alternatives, enhanced ill-structured problem-solving performance (e.g., Mumford et al., 1993; Shin et al., 2003), presumably through activating higher-order thinking skills. Base on this connection, there is the possibility that intentional use of higher-order thinking skills will help cultivate the learners’ dispositions. In addition, studies showed that the ability to regulate cognition through planning, monitoring, and evaluation stimulated learners’ conscious consideration of multiple goals, constraints, and solutions in ill-structured problem solving (e.g., Reiter-Palmon, Mumford, O’Connor Boes, & Runco 1997; Shin et al., 2003).

From a theoretical perspective, Bloom (1956) argued that by engaging in activities requiring complex intellectual
abilities and skills, learners will become more conscious and aware of the cognitive behavior they exhibit. Similar to domain knowledge and dispositions, metacognition is a contributor to higher-order thinking, and the operation of higher-order thinking skills may in turn increase learners’ metacognitive consciousness and awareness.

Higher-Order Thinking in Ill-Structured Problem Solving

As ill-structured problems are characterized by undefined problem space, multiple representations and solutions, and unclear evaluation criteria (Jonassen, 1997), higher-order thinking skills should play a pivotal role in resolving these uncertainties. In order to identify the roles of analytic, generative, and evaluative thinking skills during ill-structured problem-solving process, four types of ill-structured problem-solving models that perceive ill-structuredness from different perspectives were reviewed: 1) classic model (Sinnott, 1989; Voss, 1988), 2) instruction-oriented model (Jonassen, 1997), 3) design problem solving model (Geol & Pirolli, 1989, 1992), and 4) creative problem solving model (Mumford, Mobley, Reiter-Palmon, Uhlman, & Doares, 1991; Treffinger, 1995). Additionally, studies that found higher-order thinking skills an important predictor of ill-structured problem-solving performance were also analyzed for corroboration and complementation. Based on analysis, the analytic, generative, and evaluative thinking skills required during problem identification and solution generation were derived (see Appendix B for outline).

Analytic Thinking in Problem Identification

Analyzing the given and hidden information in the problem space is the first step of problem identification. The problem solver should identify not only the surface level elements such as initial state, goals, operators, constraints, etc. (Geol & Pirolli, 1989; Voss, 1988) but also the unstated problems, goals, assumptions, and perspectives (Jonassen, 1997). Relevant schemata or categories should be searched and retrieved from prior knowledge to encode the available information and to guide further data finding (Geol & Pirolli, 1989; Jonassen, 1997; Mumford et al., 1991). Lee & Cho (2007) found that better problem finders tend not to confine themselves to the given information, but try to revive maximum knowledge to structuralize the situation or to search divergently for new information beyond what is suggested, depending on how ill-structured the problem was. In addition, the problem solver should also analyze the relationships among the identified elements, such as causal relationships, classifications, and knowledge-context connections (Jonassen, 1997; Treffinger, 1995; Voss, 1988).

Generative Thinking in Problem Identification

Proposing new operators and constructing problem representations extend analytic thinking by generating new meanings. In addition to encoding information, retrieved schemata or categories can also be instantiated into operators with the contextual information to compensate for the missing elements in the problem space (Geol & Pirolli, 1992). When the perceived problem elements point to one unique direction, the solver can represent and solve the problem through convergent production, as is commonly seen in experts’ problem-solving activities (Voss & Post, 1989). However, a more typical way of framing ill-structured problems is to generate multiple, alternative representations from different perspectives and converge on the most appropriate representation (Jonassen, 1997; Sinnott, 1989; Treffinger, 1995; Voss, 1988). Studies on problem construction indicated that solvers who wrote down all possible problem statements and finally reframed the problem were more likely to develop high-quality solutions, especially in working on unfamiliar problems (e.g., Redmon, Mumford, & Teach, 1993; Reiter-Palmon et al., 1997).

Evaluative Thinking in Problem Identification

Evaluative thinking assists analytic thinking during problem analysis and assists generative thinking during problem construction. To efficiently specify the problem space, the solver needs to attend selectively to the available information and the activated schemata by evaluating their internal consistencies and relevance to goals (Jonassen, 1997; Mumford et al., 1991; Sinnott, 1989). Studies found that the problem solver’s abilities to distinguish relevant from irrelevant information and to select best-fitting concepts or categories to understand the problem situation are significant predictors of solution quality and originality (e.g., Mumford et al., 1996, 1997). With multiple problem representations, the solver also needs to evaluate and select among the competing options based on his or her
perceptions and ultimate goals (Jonassen, 1997; Sinnott, 1989; Treffinger, 1995), and at times to negotiate the problem space boundaries based on the constraints (Geol & Pirolli, 1992). Although there is no clear empirical evidence, the evolving process from divergent to convergent problem representation should involve evaluative thinking.

**Analytic Thinking in Solution Generation**

To generate high-quality solutions, the solver should use analytic thinking to facilitate ideation and justification. By analyzing links among the selected coding categories and further identifying remotely associated categories, the solver will be inspired to generate better solution ideas (Mumford et al., 1991; Treffinger, 1995). Studies on ill-structured problem-solving strategies found that when solvers were suggested to analyze the categories of potential solutions or to search for remotely associated categories in familiar domains, they tended to produce more high-quality ideas (e.g., Butler & Kline, 1998; Stoyanov & Kirschner, 2007). Moreover, for large-size problems, the solver should decompose the entire problem into components and analyze their connections so as to generate partial solutions and combine them at a later stage (Geol & Pirolli, 1992). Additionally, after generating solutions, it is important for the solver to justify the preferred solutions by identifying relevant facts, evidence, statements, and conjectures to warrant their claims (Jonassen, 1997; Voss & Post, 1989), the analysis of which is essential to ill-structured problem solving (Shin et al., 2003).

**Generative Thinking in Solution Generation**

All the previous higher-order thinking activities are preparing for applying generative thinking to develop solutions. For highly ill-structured problems with multiple representations, there is the need to generate multiple, alternative solutions through divergent production (Jonassen, 1997; Sinnott, 1989; Treffinger, 1995; Voss & Post, 1989). Although it is difficult to generate fluent solution ideas to complex problems, especially for novices (Jonassen, 1997), two empirically-validated strategies might be used. First, through combining and reorganizing the categories analyzed in the previous stage, the solver may break the fixed paradigms and come up with new categories that support solution generation (Butler & Kline, 1998; Mumford et al., 1991; Stoyanov & Kirschner, 2007). Second, the solver may also generate multiple, better solutions by considering the perspectives of different stakeholders involved in the problem (Butler & Kline, 1998; Choi & Lee, 2009; Jonassen, 1997). However, convergent production is more effective for generating one unique or relatively fewer solutions in problem situations with specific representations (Diakidoy et al., 2001; Voss & Post, 1989). Convergent production should also be used during and after divergent production, as the problem-solving process evolves from exploring divergent ideas to converging on the promising solutions (Jaarsveld et al., 2005), constructing evidence-based arguments to justify decisions (Jonassen, 1997; Shin et al., 2003), and incrementally adding details to refine the final solution (Geol & Pirolli, 1992).

**Evaluative Thinking in Solution Generation**

Evaluative thinking in solution generation has both formative and summative natures. From the formative sense, the solver should evaluate the interim solution ideas while proposing and refining them to satisfy the goals at hand and to stay within the constraints (Baer, 2003; Mumford et al., 1991). Divergent production using the two strategies mentioned earlier involves evaluative thinking, as the solver needs to generate ideas fitting certain categories or perspectives, leading to more meaningful solutions (Butler & Kline, 1998; Stoyanov & Kirschner, 2007). Also, design problem solving study found that the incremental design process was integrated with generation, evaluation, and modification of design components based on contextual factors (Geol & Pirolli, 1992). From the summative sense, the solver has to either select from or narrow down the multiple solutions by evaluating them with explicit internal and external criteria (Jonassen, 1997; Sinnott, 1989; Treffinger, 1995; Voss, 1988). While moving from divergent to convergent production and justifications, good problem solvers weigh the solution alternatives and their potential outcomes against the internal constraints and ultimate goals to decide on the most defensible and appropriate solutions (Jaarsveld & van Leeuwenb, 2005; Shin et al., 2003).

As can be seen, analytic, generative, and evaluative thinking skills each plays a unique role in problem identification and solution generation. At the same time, they are inseparable and well-integrated into the ill-
structured problem-solving process. Since the sub skills involved in the three types of higher-order thinking are not used sequentially, intelligent problem solvers will apply them flexibly by switching to proper skills within or across the categories and phases based on the situation.

**Scaffolding Higher-Order Thinking in Ill-Structured Problem Solving**

After instantiating the higher-order thinking skills in ill-structured problem solving, the most important task is to use theory and research on scaffolding to develop those skills in novices so as to improve their problem-solving performance. How can we use scaffolding features, types, and functions to enhance higher-order thinking skills? How can we design the scaffolds to address the challenges reported by previous studies? How can we help learners sustain and transfer the skills developed under scaffolding? These questions could be best answered by design-based research (Barab & Squire, 2004; Brown, 1992). As a beginning, this framework will present some preliminary thoughts based on existing theory and research.

**Scaffolding Features**

Scaffolding was originally defined as an adult or expert interacts with a child or novice to help him or her achieve a goal beyond his or her unassisted efforts (Wood, Bruner, & Ross, 1976). This metaphor has been generalized to structures that interact with novice learners to help them accomplish tasks beyond their competencies (Puntambekar & Hubscher, 2005; Reiser, 2004). According to Puntambekar and Hubscher (2005), the current notion of scaffolding has the following features: shared understanding, scaffolder, ongoing diagnosis, calibrated support, and fading. These features can delineate the scaffolding for higher-order thinking during ill-structured problem solving at a macro level.

Shared understanding between the learners and the scaffolder regarding the goal of the activity is critical for the learners to gain ownership of the task (Puntambekar & Hubscher, 2005). In the current context, the learners and the scaffolder should have a common understanding of solving ill-structured problems with higher-order thinking skills. Real-world problem situations will establish the overarching goal of problem solving in the learning environment. Moreover, simplified activities of applying higher-order thinking to problem solving might be used for preparing learners with shared understanding (e.g., Kolodner, Crismond, & Fasse et al., 2003; Reiser, Tabak, & Sandoval et al., 2001).

The role of scaffolder has been extended from more knowledgeable others to include technology tools and resources, advancing the techniques of providing instructional supports (Lajoie, 2005; Puntambekar & Hubscher, 2005). Technology and human scaffolds are mutually beneficial because the technology scaffold can provide routine supports to common learning needs, allowing time and efforts for the human scaffold to provide on-demand, customized support that may not be easily provided by the technology scaffold (Saye & Brush, 2002; Sharma & Hannafin, 2007). Because of the complex learning involved in higher-order thinking and ill-structured problem solving, “mixed initiative” designs based on the synergy of technology and human supports might be particularly helpful (Pea, 2004, p. 444).

The process of scaffolding, including ongoing diagnosis, calibrated support, and fading are essential yet largely overlooked in current design and implementation of scaffolding (Pea, 2004; Puntambekar & Hubscher, 2005). The scaffolder should monitor the learners’ current levels of understanding in order to provide “graduated assistance” (Stone, 1998) and to gradually fade the scaffolds to let the learners takeover the responsibility, which is a process of “internalization” (Vygotsky, 1978). To compensate the technological limitations in dynamically calibrating and fading supports, redundancies in technology scaffolds can provide graduated assistance (Puntambekar & Hubscher, 2005), and human scaffolders can assess learners’ performance to adjust the levels of both human and technology scaffolding (Pea, 2004). Therefore, in designing mixed scaffolds for the current context, technology may create multiple forms and levels of scaffolding to meet learners’ developmental needs in higher-order thinking and ill-structured problem solving, and the human scaffolders (e.g., instructor, peers) may select and fade the scaffolds based on ongoing diagnosis of the learners’ progress.

**Scaffolding Types and Functions**

According to the literature, scaffolding types include hard, fixed scaffolds and soft, dynamic scaffolds (Saye & Brush, 2002; Wang & Hannafin, 2008). The former are planned in advance based on the cognitive activities involved in the task and the difficulties learners might encounter. They are usually explicit, non-negotiable, and mediated by technology to constrain learners’ actions (Sharma & Hannafin, 2007). The latter are created
dynamically within certain situations. They are more customized and adaptive to individual learners, mainly provided by instructors, experts, or peers through dialogic interactions (Saye & Brush, 2002). The two types of scaffolds parallel the two complimentary scaffolders – technology and human – mentioned earlier.

Hannafin, Land, and Oliver (1999) classified scaffolds into four functions that support student learning in open-ended learning environments: conceptual (what knowledge to consider), metacognitive (how to think about the problem), procedural (how to use learning environment features), and strategic (what are the alternative strategies) scaffolds. The procedural scaffolds were later defined as operational steps or cognitive structures for helping students complete a task (Sharma & Hannafin, 2007; Wang & Hannafin, 2008). The above two types and four functions of scaffolding, which emphasize the ways and purposes of creating scaffolds, can guide the micro level conceptualization of instructional support for enhancing the three higher-order thinking skills during ill-structured problem solving.

**Conceptual scaffolds.** They help learners identify conceptual knowledge related to a problem and create structures of conceptual organization (Hannafin et al., 1999). These functions are consistent with analytic thinking, as the solver has to retrieve relevant schema or categories from prior knowledge for encoding information and to figure out the organization among the problem space elements, sub problems, solution categories, and evidence of claims. Hard conceptual scaffolds such as links to available resources, concept maps, and relationship prompts can facilitate learners’ knowledge retrieval and problem analysis. Chen & Bradshaw (2007) and Oliver & Hannafin (2000) used advanced organizers to help students consider the associated knowledge concepts and relationships in solving problems. They both found the students were able to identify and analyze the relevant knowledge but the younger learners have difficulty integrating them into the problem. Soft scaffolds in the form of individualized suggestions, feedback, or questioning on concepts selection and structure analysis may further learners’ understanding of knowledge and its applications in problem contexts.

**Procedural scaffolds.** They provide operational sequences of thinking or completing a task and use structures to focus and sustain learners’ activities (Sharma & Hannafin, 2007; Wang & Hannafin, 2008). Ill-structured problem solving contains general procedures of using analytic, generative, and evaluative thinking to identify problems and generate solutions. Procedural scaffolding can guide learners through the problem-solving process integrated with different types of thinking, providing the basis for them to internalize and self-regulate those thinking skills. Hard scaffolds such as question prompts and sentence starters were commonly used for procedural scaffolding. However, they are usually insufficient as they may lead to a piecemeal approach to learning (Davis & Linn, 2000) or induce dependence (Oliver & Hannafin, 2000), and learners with different competencies have different needs for procedural guidance (Ge et al., 2005). Soft scaffolds such as instructor-student interactions should not only attend to the emergent needs for procedural support (Wang & Hannafin, 2008) but also monitor the learners’ progress and adjust or fade the hard scaffolds at appropriate times to encourage internalization.

**Metacognitive scaffolds.** They guide the ways to think about the problem and remind the learners to reflect on the goals and monitor the learning process (Hannafin et al., 1999). In order to use analytic, generative, and evaluative thinking skills purposefully and effectively, novice problem solvers need metacognitive scaffolds to help them understand the role of each type of thinking at different problem-solving stages and consciously use those thinking skills through planning, monitoring, and evaluation, until they achieve automation. Hard metacognitive scaffolds such as question prompts and hints have been frequently integrated into procedural scaffolds to help students regulate their problem-solving process (e.g., Davis & Linn, 2000; Ge et al., 2005). However, studies showed that learners may experience difficulty or show reluctance in using metacognitive scaffolds, which are less prescriptive and require more efforts to grasp (e.g., Oliver & Hannafin, 2000; Manlove et al., 2007). Soft scaffolds based on ongoing diagnosis of learners’ performance are more likely to improve achievements (e.g., Azevedo, Cromley, Winters, Moos, & Greene, 2005; Greene & Land, 2000) and may serve as “metascaffolding” of how to use the hard scaffolds (Pea, 2004).

**Strategic scaffolds.** They suggest alternative approaches to a problem or task and help learners identify and evaluate needed information, resources, or tactics (Hannafin et al., 1999; Wang & Hannafin, 2008). Strategic scaffolds may be particularly useful for generative thinking, as they expose the learners to alternative perspectives or solutions and provide them tactics for divergent and convergent production. It may also assist analytic thinking by recommending useful recourses and support evaluative thinking by suggesting important evaluation criteria. Choi & Lee (2009) provided multiple experts’ solutions to facilitate problem solving and found the learners began to acknowledge the different perspectives but still failed to evaluate and integrate them to build their own perspective. Oliver & Hannafin (2000) used strategic scaffolds for helping learners evaluate solutions generated from divergent production, but most students glossed over those scaffolds by selecting a predetermined solution. Soft scaffolds might be used to draw learners’ attention to appropriate use of the hard strategic scaffolds as well as to provide dynamic, individualized strategic scaffolds that are tailored to each learner.
Implications

This framework is designed to guide the inquiry of scaffolding ill-structured problem solving with a focus on 1) learners’ difficulties in performing higher-order thinking, 2) their misunderstanding and misuse of the scaffolds, and 3) unsustainable or non-transferable problem-solving skills. The higher-order thinking skills and scaffolding features, types, and functions identified in the framework have the potential to address these major issues.

Learners’ vague ideas about the types of thinking required during ill-structured problem solving may lead to lower-order thinking. By situating analytic, generative, and evaluative thinking skills in ill-structured problem solving and providing procedural and metacognitive scaffolds, the learners will be able to understand why and how to apply the specific skills and to learn to actively regulate their performance. Conceptual and strategic scaffolds may facilitate analytic and generative thinking in particular through activating the learners’ prior knowledge and offering resources or tactics. Additionally, guided higher-order thinking may help cultivate desirable dispositions and beliefs in the long term.

According to previous studies, the scaffolds misunderstood or used superficially by the learners were usually hard, static scaffolds. In order to help learners recognize the scaffolds’ strategic functions and benefit from more flexible scaffolding, it would be helpful to integrate soft, dynamic scaffolds provided by human tutors or peers. Scaffolding in the form of social interactions will not only provide adaptive supports based on ongoing diagnosis of the learners’ level of understanding, but also promote the learners’ appropriate use of hard scaffolds through “metascaffolding” (Pea, 2004).

Gradually fading the scaffolds is necessary to develop learners’ sustainable problem-solving skills and can be best achieved by mixed scaffolding design. Although technology-based hard scaffolds may not fade intelligently, the human scaffold can accomplish this task by adjusting the functions or levels of hard scaffolds to fit the learners’ current zone of proximal development. Moreover, problem-solving skills developed within this framework may have better transferability, because as the essential components of ill-structured problem-solving competencies, the analytic, generative, and evaluative thinking skills can be generalized and reused for different problem contexts.

Although this framework is grounded in theory and research on higher-order thinking, ill-structured problem solving, and scaffolding, there is still much unknown about the synergy of the three theoretical perspectives and their contribution to facilitating novices’ ill-structured problem-solving activities. Therefore, empirical studies should be conducted in ill-structured domains to validate and refine this framework.
References


