COGNITIVE AND METACOGNITIVE PROMPTING IN ILL-STRUCTURED TASKS: THE ART OF ASKING

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Abstract

This review of prompting and its applications within ill-structured problems connects a number of literature/research bases to derive prompting principles that foster learning and skill acquisition among trainees/novices performing complex, ill-structured problem-solving tasks. Relevant theoretical inputs and research are reviewed, from which a practical model is derived outlining how reflective metacognitive prompting can support learning and the adoption of an internalized learning approach. Future research should aim to empirically test the proposed model.

Introduction

The present paper attempts to connect the literatures on ill-structured problems, developing competence/expertise, metacognition, and scaffolding (in particular prompts). Such an undertaking should prove informative in the scaffolding of novice problem-solving in ill-structured environments. Consideration is given to laying the groundwork for continual development with the aim of instilling metacognitive strategies for continued exploitation beyond taught environments. The remainder of this introduction outlines the relevant literature bases. A prompting method is then developed and proposed alongside some considerations for its implementation within technology enhanced learning environments.

Problem Structure

Many researchers have highlighted the crucial features, differences, and distinctions between well-structured and ill-structured problem-solving tasks (Byun, Lee, & Cerrato, 2014; Ge & Land, 2004; Ge, Chen, & Davis, 2005; Kim & Hannafin, 2011; Krizan, 1999; Lynch, Ashley, Pinkwart, & Aleven, 2009; Pirolli & Card, 2005). Generally, an *ill-structured problem* has vague goals, unclear solution pathways, undefined problem spaces/domains, and no best solution method. Lynch et al. (2009) characterise ill-structured problems as lacking some definition or being intractable, both of which require the problem solver to characterise aspects of the problem before solutions can be developed. Examples of problems or domains that lack clear definition include scientific enquiry, design problems, intelligence analysis, decision-making, troubleshooting, dilemmas, and policy problems (Kim & Hannafin, 2011, Pirolli & Card, 2005). Solving such problems is complex and poses higher demands on cognitive and metacognitive ability (Ge et al., 2005).

Table 1 captures and categorises some of the crucial distinctions between well-structured problems and problems lacking various degrees of structure (partly adapted from Krizan, 1999). Also captured are some distinctions in the higher-order cognitive skills attributed to effective performance for problems of differing structure (Ge & Land, 2004). Some of the skills listed are interrelated. For instance, critical thinking and metacognition exhibit considerable overlap (e.g., Helsdingen, van den Bosch, van Gog, & van Merriënboer, 2010), with metacognition underpinning the ability to think critically. Other skills represent either stages of sensemaking or solution generation (e.g., Pirolli & Card, 2005). *Sensemaking* involves a series of activities that focus on constructing an understanding of the problem and problem domain and may incorporate problem definition, structuring the problem space and finding an appropriate way to represent the problem. Table 1 indicates that as the level of problem structure decreases, an increasing number of higher-order cognitive skills are needed for efficient problem solving, which may be problematic for novices.

Table 1

Key Characteristics and Cognitive Processes as a Result of Problem Structure

Features	**Problem Structure**			
	Well-structured	Semi-structured	Ill-structured	Severely ill-structured
Typical problem	How much/ many?	Determine best configuration, or rank outcomes	Identify outcomes in an unbounded context	Predictive identification of outcomes in a dynamic situation
Role of facts	High	Moderate	Low	Lowest
Role of judgment	Low	Moderate	High	Highest
Probability of error	Low	Moderate	High	Highest
Higher-order cognitive processes		Problem structuring Problem representation Alternate generation Evaluation Critical thinking Metacognition	Problem definition Problem structuring Problem representation Alternate generation Evaluation Mental simulation Critical thinking Metacognition Expert intuition /recognition	Problem definition Dynamic reframing Problem structuring Problem representation Alternate generation Evaluation Mental simulation Critical thinking Metacognition Expert intuition /recognition Foresight

Novice-Expert Distinctions

Novices differ from domain experts in the way in which they approach an ill-structured problem (Vogel-Walcutt, Fiorella, & Malone, 2013). Novices tend to over-simplify problems by selecting a sub-set of components to attend to, they often have difficulty in identifying the relevance of problem information, and they may fail to consider alternative solutions (An & Cao, 2014; Kim & Hannafin, 2011). Novices may not take time to explore the problem or engage in planning activities and may prematurely skip to developing a solution (Roll, Holmes, Day, & Bonn, 2012, Ge et al., 2005) as their knowledge and solution strategies are not interconnected (Vogel-Walcutt, Fiore, Bowers, & Nicholson, 2009). Novices are more likely to make unfounded assumptions and be unwilling to abandon non-productive strategies (Kim & Hannafin, 2011). Finally, novices do not tend to monitor or evaluate their strategizing and rarely spontaneously engage in metacognitive activities (An & Cao, 2014; Roll et al., 2012). In contrast, experts have well-developed schemata that help organise and structure their problem framing activities. They are quick to recognise salient problem features/cues and generate appropriate solutions (Klein, 2090). Experts are also better aware of when they have made errors and will adjust their strategies accordingly (Ge & Land, 2004), demonstrating an improved ability to monitor and evaluate their performance, indicative of the application of metacognitive skill.

Models of expert behaviour state that expertise is acquired by learning the basic domain knowledge, the appropriate procedures, and then engaging in extensive and varied practice whereby knowledge management improves and the frequency of errors decreases (Fitts & Posner, 1967). Increase in competence is consolidated via reflective and integrative metacognitive practices that help identify strengths and weaknesses in the problem-solving approach in order to consolidate effective strategies and explore the mitigation of ineffective ones (Baartman & de Bruijn, 2011).

Metacognition

As indicated by previous sections, metacognitive ability underlies effective performance in many ill-structured domains (Lai, 2011). Metacognition refers to an awareness of one's own cognitive processes, along with knowledge and regulation of appropriate cognitive strategies (Schraw & Dennison, 1994). Metacognition incorporates activities such as planning, monitoring and evaluation, and can be implemented before, during, or after a problem-solving or learning episode (Vogel-Walcutt et al., 2013). An important distinction can be made between metacognitive reflection after, and metacognition within a problem-solving episode (Schön, 1983; Eraut, 1994). Reflection metacognition after the problem-solving episode is aimed at explicitly identify the cognitive strategies and decisions made during a problem-solving episode as well as learning about their relative strengths and weaknesses. Such activities help consolidate knowledge and identify relevant cues that can then be anticipated in future problem-solving activities (Dinsmore, Alexander, & Loughlin, 2008). On the other hand, metacognition within a problem-solving episode refers to the monitoring and regulation of cognition whilst engaging in problem-solving activities, making use of relevant contextual cues and knowledge concerning strategies to enable better decision-making. Such activities are indicative of growing competence within a domain.

From a novice perspective, there are differing cognitive load considerations (Sweller, 1994) for each approach. Metacognition within a problem-solving task places additional cognitive load on limited mental resources that may already be overwhelmed with the processing of task-relevant information. Such activities, when based around no/scant previous experience and little relevant knowledge can prove ineffective. However, metacognitive reflection after a learning episode enables a novice learner to evaluate their performance once cognitive load has eased. With repetitive practice, key evaluative principles will be assimilated into schemata that will activate relevant knowledge and aid in the processing of problem information in subsequent problem-solving episodes. As a result, cognitive load is lightened and spare mental resources can be dedicated to monitoring and regulating cognitive processes within the learning episode. As such, reflective metacognition may act as a precursor to metacognitive monitoring, prompting subsequent self-regulation, with iterative cycles of reflection and improved self-regulation (Berthold, Moore, Steiner, et al., 2012; Sitzmann & Ely, 2010). Notwithstanding their different applications, both metacognitive approaches emphasise learning through learner-environment interaction (Dinsmore et al., 2008), and authentic practice opportunities are vital to supporting the efficacy of metacognitive applications (Coulson & Harvey, 2013; Halpern, 1998).

Scaffolding and Prompts

The principle of scaffolding has been developed around the notion of a *zone* of *proximal development* (ZPD: see Wood, Bruner, & Ross, 1976; Vygotsky, 1980). The ZPD represents the gap between a learner's current performance, and the level of performance that can be supported through assistance. Scaffolding can take many forms. The method developed presently adopts the form of a series of prompts (targeted questions), that when considered collectively, constitute a scaffolding technique (Holden & Sinatra, 2014) combining cognitive and metacognitive strategies that a learner/trainee can adapt and utilise as required. In doing so, the application of our method employs both hard and soft scaffolding techniques (An & Cao, 2014). Hard prompts are those that can readily be planned and anticipated, whereas soft scaffolds are more dynamic in nature and reflect the need to tailor scaffolds to the learner's experience and the structure of the task.

Such an approach has two main benefits. Firstly, in ill-structured and uncertain environments prompts generate explicit and actionable feedback by guiding individuals to explicitly evaluate key problem-solving decisions and concepts. Where feedback indicates good performance, the additional information generated can be consolidated into appropriate schemata and may help to mark crucial task features for future recognition and exploitation (Byun et al., 2014; Ge et al., 2005; Halpern, 1998; Kim & Hannafin, 2011). Where feedback indicates ineffective performance, prompts can be used to uncover and explore the causes of any faulty reasoning (Kim & Hannafin, 2011), and strategies can be developed to mitigate future errors. Secondly, an additional benefit of prompts is in teaching metacognitive skill to novices. A small body of research in ill-structured contexts suggests that novices demonstrate improved problem-solving performance when exposed to metacognitive scaffolding (e.g., Ge & Land, 2003; Roll et al., 2012; Vogel-Walcutt et al., 2009), that metacognitive skill can be taught (e.g., Coulson & Harvey, 2013; Vogel-Walcutt et al., 2009), and that metacognitive activity continues once scaffolding has been removed (Roll et al., 2012). Byun et al. (2014) suggest that prompts can act as explicit processing guidelines that can be assimilated into a problem-solving schema and applied to novel problems (Byun et al., 2014). In doing so, scaffolding has equipped the learner with a technique that they can exploit (Holton & Sinatra, 2014). Such notions have been captured under terminology such as a *self-scaffolding heuristic* (Holton & Clarke, 2006) and metacognitive mindsets Roll et al., 2012).

Development of a Model

The previous review of relevant literature bases, whilst not exhaustive, can be drawn together to derive principles and scaffolding content that should foster learning among novices performing ill-structured problem-solving tasks. Table 2 presents a list of prompts, aligned to the required higher-order cognitive processes required of severely ill-structured problems. To adapt to semi-structured and ill-structured tasks simply omit prompts aligned to cognitive processes not required of tasks of that structure (see Table 1.).

Table 2

Scaffolding Prompts for Severely Ill-Structured Tasks

Higher-order cognitive process	**Reflective scaffolding prompts (after problem-solving)**	**Scaffolding prompts (within problem-solving)**
Problem definition	• How did you identify gaps in your understanding of the problem? • What efforts were made to understand the problem before you developed solutions? What more could have been done? • How did you determine essential and desirable solution features?	• What are the gaps in your /my understanding of the problem? How can you fill them? • What features must my solution incorporate? What else could be included?
Problem structuring	• How did you formulate appropriate goals? How could this be improved? • How did you plan to accomplish your goals? How effective was your planning? • How did you determine what information was relevant to the problem? What other information would have been useful?	• What are my goals? Are they appropriate? • What relevant information do I need?
Problem representation	• What format(s) (e.g., tables, pictures) did you use to capture important problem information? How appropriate was this? What might you do differently?	• Am I capturing my task efforts in an appropriate format?
Dynamic reframing	• Describe any instances in which you had to re-examine your problem definition. Why did this happen? • Describe any instances where you had to revise your task goals. Why did this happen?	• Do I need to revise my goals?
Alternate generation	• What efforts were made to generate alternative solutions? Were they sufficient? • What other lines of inquiry could have been pursued?	• What other options are feasible? Are they worth pursuing? Are there any obvious flaws?

Table 2 *Scaffolding Prompts for Severely Ill-Structured Tasks* (continued)

Higher-order cognitive process	**Reflective scaffolding prompts (after problem-solving)**	**Scaffolding prompts (within problem-solving)**
Evaluation	• What criteria did you use when evaluating your solutions? • Why did you select this solution? What were its strengths and weaknesses?	• Does my preferred solution meet all of the problem requirements? Can it be improved?
Mental simulation	• What efforts were made to test your solution for errors? What more could have been done?	• How can I test my solution?
Critical thinking	• What relevant information was missing? ▪ *Information problems:* What assumptions were made or what theories were constructed to fill information gaps? Were these assumptions/theories challenged? ▪ *Design problems:* Or what constraints/restrictions were implemented to enable a solution to be reached? Were constraints/ restrictions revised at any point? • Given more time/resources, what further efforts could you make to improve upon your solution?	• Am I missing any crucial information? • Do I need more time/resources?
General metacognition	• What were the advantages of your problem-solving approach? • What were the weaknesses of your problem-solving approach? What errors were made? What could have been done differently?	• What are the strengths and weaknesses of my problem-solving approach? •
Engendering better intuition/ recognition	• What errors/misunderstandings occurred during problem-solving? Why did these occur? How could they be avoided? • Did the problem bear any resemblance to other problems you have encountered? What are the similarities and differences?	• Does the problem bear any resemblance to other problems?
Foresight	• What further information is needed to better anticipate whether your solution will remain robust/relevant? How might you anticipate this?	• How can I ensure my solution is robust?

The reflective prompts in the model combine a number of sensemaking and solution-focused prompts with other cognitive processes often demonstrated by experts. Whilst this list is somewhat extensive, novice learners will benefit from early exposure to all categories of prompts following some initial problem-solving experience. Here, reflective principles can be learned and practiced in a well-timed fashion so that cognitive load remains manageable. Once reflective principles have been practiced a number of times, it should be possible to select a smaller subset of prompts to cue and maintain an improved level of cognitive strategizing. Also listed in Table 2 are a number of prompts for scaffolding cognitive and metacognitive activity during a problem-solving episode (Schön, 1983; Eraut, 1994). This list of scaffolding prompts demonstrates the self-regulatory principles that a learner could adopt to monitor and hone their cognitive strategies within a problem-solving episode. This set of prompts is necessarily smaller in order to minimise the additional cognitive processing load

Guidelines for Implementation

There are a number of scaffolding principles that should, wherever possible, be implemented alongside a set of prompts. These are outlined below:

- Care should be taken to promote the benefits of prompts, including the *metacognitive mindset* that can be instilled, at the point where the learner is initially exposed to a prompts (Ge et al., 2005; Roll et al., 2012). This should act to encourage engagement with the prompts and can increase motivation to learn within practice opportunities.
- The learner may require additional support when first exposed to reflective prompts, and additional support may be required when first attempting to engage in within problem metacognition using scaffolding prompts. Worked examples and modelling may fulfil this purpose (Coulson & Harvey, 2013).
- The learner should be made aware that prompts will be gradually withdrawn. The planned withdrawal of support should create an impetus for the learner to switch from relying on prompts to structure their thinking to actively internalising prompts and the principles they instil in order to structure their own generative learning techniques. Setting such expectations aids in promoting the adoption of self-regulatory processes.
- The method detailed presently was developed in order to be generically applicable to a wide-range of ill-structured tasks in a variety of domains. As such, some of the prompts may need some small semantic adjustments in order to more closely align the prompts with the context.
- An additional benefit of the present method is its potential for exploitation in group settings (e.g., Byun et al., 2014). The lines of cognitive enquiry promoted by prompts may act as discussion points between group members. Such dialogue can aid in attaining a greater depth of problem understanding, identifying misunderstandings, and generating more relevant knowledge.

Conclusions

The present paper has drawn together a number of literature bases in order to propose a model for scaffolding cognitive and metacognitive activities in ill-structured problems. In conjunction with the model, some guidelines concerning its implementation have been proposed. The remainder of this paper outlines implications for technology enhanced learning environments. An essential feature of these environments is that they support interactivity between learners, the system, and tutors. Some potential limitations of prompting methods along with avenues for future research are addressed.

The methods and techniques proposed here can be assimilated into computerised learning materials or, for example, online blended learning activities where there is communication between learners and support functions (i.e., peers, tutors, and the system). There is some evidence that prompting can be beneficial in simulated training environments (Berthold et al., 2012; Vogel-Walcutt et al., 2009). There are also numerous researchers that advocate the use of scaffolding prompts in web-based learning environments (e.g., Ge et al., 2005), and within cognitive tutoring systems (e.g., Roll, Aleven, McLaren, & Koedinger, 2007).

There are a number of limitations to the use of question prompts, identified by Byun et al. (2014) that could impact on prompting. Firstly, prompts may be ignored or answered superficially. This may be especially problematic in distance learning environments where the level of perceived accountability is diminished. Whilst promoting the benefits of scaffolding and prompts early on may improve the level of engagement with prompts, consideration should be given to methods of capturing and auditing a learners prompted responses. Secondly, some prompts can only be answered if the relevant level of knowledge is held. Whilst the present method has been designed to be generic to novices within multiple problem-solving domains, it may be that there will be a minimal number of practice trials before the learner is confident that they can respond to prompts appropriately. This minimal level may fluctuate from learner to learner. Learners should be made aware that in ill-structured problems there are no correct answers and that answering prompts will engender greater understanding. Information concerning individual differences could also be incorporated into an introduction in order to motivate learners to persist with attempting to answer prompts. A final limitation is that exhaustive and overly complex prompts may reduce motivation. Once again, promoting the utility of prompts may mitigate such effects and highlighting the gradual withdrawal of structured prompting as the learner becomes responsible for regulating their own generative learning episodes.

A primary focus of future research will be to test and refine the model proposed presently. Such an undertaking would require examination of problems of varying degrees of structure (as depicted in Table 1) and within varying domains. Control comparisons should be utilised where possible, given due ethical considerations. Secondly, closer examination of the depth and timing of prompt engagement could prove fruitful in refining scaffolding guidelines.

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