

Sensemaking and metacognitive prompting in ill-structured problems

Abstract

Purpose – This paper develops a set of generic prompting principles and a framework of prompts that have the potential to foster learning and skill acquisition among adult novices when performing complex, ill-structured problems.

Design/methodology/approach – Relevant research in the literatures surrounding problem structure, sensemaking, expertise, metacognition, scaffolding and cognitive load were reviewed and synthesised in order to derive generic prompting principles and guidelines for their implementation.

Findings – A framework of generic principles and prompts is proposed. Differentiation between prompts supporting cognition either within, or after an ill-structured problem-solving task was supported.

Practical implications – Prompts such as those proposed in the framework developed presently can be designed into technology-enhanced learning environments in order to structure and guide the cognitive processes of novices. In addition, prompts can be combined with other learning support technologies (e.g., research diaries, collaborative discourse) in order to support learning. Empirical testing will be required to quantify the potential benefits (and limitations of) the proposed prompting framework.

Originality/value – The prompts developed constitute a framework for structuring and guiding learning efforts in domains where explicit, actionable feedback is often unavailable. The proposed framework offers a method of tailoring the scaffolding of prompts in order to support differing levels of problem structure and may serve as the basis for establishing an

internalised and adaptive learning approach that can be transferred to new problems or contexts.

Keywords – Sensemaking, Metacognition, Problem structure, Scaffolding, Prompts, Cognitive load

Paper type – Conceptual paper

Introduction

Ill-structured problems are complex and require the integration of various cognitive and metacognitive skills. Considerable efforts are required before efficient performance emerges. However, there is evidence to suggest that learning follows from deliberate practice supported by feedback provision and metacognitive reflection (e.g., Baartman & de Bruijn, 2011; Hoffman et al., 2012; Kim et al., 2013; Kolb & Kolb, 2009; Kuiper & Pesut, 2004). The present paper is an attempt to connect and synthesise the relevant literature on problem structure, sensemaking, expertise, metacognition, scaffolding (in particular prompts), and cognitive load in order to derive a set of generic prompting principles that could support and accelerate learning among novices when solving ill-structured problems. Relevant theoretical inputs are reviewed and a method outlining how appropriate scaffolding can support learning and the adoption of an internalised learning approach is proposed. Consideration is given to laying the groundwork for continual development with the aim of instilling effective problem-solving strategies for continued exploitation beyond the taught environment. The remaining sections of the introduction outline the relevant literature bases. Some overlap is apparent, indicating where research implications converge in ways that can inform the design or content of learning materials. A scaffolding method, comprising a series of prompts that

can be tailored to problems with various degrees of structure, is proposed in the latter half of this paper along with some key considerations for its implementation.

Problem structure

Many researchers highlight the crucial features and distinctions between well-structured and ill-structured problem-solving tasks (Byun et al, 2014; Ge & Land, 2004; Ge et al., 2005; Kim & Hannafin, 2011; Jonassen, 1997; Krizan, 1999; Lynch et al., 2009; Pirolli & Card, 2005). The majority of differences highlighted focus on knowledge of four crucial problem features: the problem domain, solution/goal criteria, solution pathways, and problem rules or principles that can direct problem-solving strategy. A well-structured problem has a clear and predictable problem domain, a known goal state, clear solution pathways and an optimal strategy for reaching the solution. In contrast, ill-structured problem-solving takes place within an undefined or unbounded problem domain, involves vague goals, unclear solution pathways, and no optimal strategy for devising a solution. Examples of problems or domains that lack clear definition and structure include scientific enquiry, design problems, intelligence analysis, decision-making, troubleshooting, dilemmas, and policy problems (Kim & Hannafin, 2011, Pirolli & Card, 2005; Sharma & Hannafin, 2007). Table 1 captures some crucial distinctions between problems of differing structure (partly informed by Krizan, 1999). Four levels of problem structure, representing a wide range of problem types, are outlined.

The degree of structure is not a stable problem characteristic. Fernandes and Simon (1999) propose that problems lie on a continuum between well and ill-structured. A task with a clearly defined problem domain could still be considered ill-structured due to a lack of definitive solution criteria or due to the problem-solver lacking knowledge of appropriate strategies for reaching a solution. Restrepo and Christiaans (2004) propose that it is possible

to impose structure upon an ill-structured task in order to ease the cognitive load of problem-solving. Structure can be gained by expending efforts towards recognising, defining, exploring and contextualising problem features. Such notions are formalised in theories of sensemaking which highlight the various cognitive activities that underpin a problem-solvers' ability to improve their degree of awareness and understanding surrounding a given problem (e.g., Klein et al., 2006a, b; Pirolli & Card, 2005).

Aligned to the differing levels of problem structure in Table 1 are the relevant sensemaking processes and principles. These include problem **defining** (exploring and/or constructing the problem domain via establishing what areas of knowledge are relevant to the problem), **structuring** (outlining problem parameters via the identification of relevant facts, constraints and solution strategies), problem **representation** (determining how to represent a problem in a way that captures problem structure and supports cognition, e.g., Kirsch, 2009) and generating potential alternate solutions (**alternate generation**) before developing the preferred solution. Sensemaking is often an iterative process (e.g., Pirolli & Card, 2005). Further sensemaking efforts may be instigated at the point wherein the problem solver recognises that their current understanding and representation of the problem is incomplete, inaccurate, or, could be reorganised to improve strategizing. Such activities, presently referred to as **reframing** (e.g., Klein et al., 2006a, b), can represent shifts in the degree of knowledge and subsequent problem structure. Generally, well-structured problems require relatively little sensemaking activities. At the opposite end of the scale, severely ill-structured problems require considerably greater sensemaking efforts and incorporate additional processes, not evident in problems with more structure. For example, **expert recognition** refers to experts' ability to recognise salient problem cues that may guide further sensemaking activity (Klein, 2009; Nemeth & Klein, 2010). Similarly, '**forecasting**' involves the identification of relevant indicators and warnings (Heuer, 1999) that serve as

sensemaking cues that an individual can use to adjust their predictions or confidence levels. Such cues can also be used to trigger problem reframing, to capitalise on advantageous courses of action, or to trigger preventative actions should the need arise.

Also captured in Table 1 are metacognitive processes and principles that enable the generation of effective problem outcomes. The following section introduces these strategies in the context of expert-novice differences (e.g., Vogel-Walcutt et al., 2013). Such differences are not specific to any particular domain or context and can prove informative when deriving generic prompting principles.

<<Insert Table 1 approximately here>>

Expertise

Experts by definition produce better quality solutions. The problem-solving processes of novices differ from those of domain experts in numerous ways. From an expert viewpoint, capturing such differences highlights effective problem-solving strategies. From a novice perspective, practical areas for targeting scaffolding interventions are highlighted. Many of the differences between novices and experts reflect interactions between acquired knowledge structures and the level of cognitive load experienced when problem-solving (Sweller, 1994). Novices need to effortfully attend to, prioritise, and encode relevant problem information. In ill-structured problems, the cognitive load experienced by novices may overwhelm their cognitive processing limitations. However, experts have well-developed knowledge structures and schemata (mental frameworks) that support the quick identification and exploitation of relevant domain experience, alleviating the level of cognitive load experienced and freeing up cognitive resources for metacognitive activity. Some key expert-novice differences in ill-structured contexts are now documented. The discussion centres on

the themes of sensemaking and metacognition followed by a brief account of how expertise is acquired.

Sensemaking. Novices have difficulty in determining the relevance of problem information and may expend little efforts in defining and structuring the problem. As such, novices tend to over-simplify problems by selecting a sub-set of features to cognitively process whilst losing sight of other important problem features/relations (An & Cao, 2014; Kim & Hannafin, 2011). It follows that novices often skip rigorous sensemaking and jump straight into developing a solution (Roll et al., 2012, Ge et al., 2005). They may do so because unlike experts, their domain knowledge and their knowledge of solution strategies are not interconnected (Vogel-Walcutt et al., 2009). In contrast, experts have well-developed schemata that support their sensemaking activities and ease cognitive load. They are quick to recognise problem cues that trigger relevant knowledge, relevant representations and effective solution strategies (Klein, 2009; Nemeth & Klein, 2010). Overall, experts spend more time sensemaking, and as a result of their improved problem exploration and understanding, generate and explore more alternate solutions than novices (Shanteau, 1992).

Metacognition. Metacognition refers to explicit awareness, knowledge, and strategic regulation of ones' own cognitive processes (Schraw & Dennison, 1994). Metacognition incorporates activities such as planning, monitoring and evaluation, and can be implemented before, during, or after a problem-solving episode (Flavell, 1979; Vogel-Walcutt et al., 2013). There is considerable debate surrounding the specific cognitive processes embodied in metacognition (e.g., Veenman et al., 2006). It can be argued that the strategic internalisation and use of sensemaking principles constitutes metacognitive activity. Whilst exacting a precise and robust conceptual definition of metacognition is beyond the scope of the present paper, the related and overlapping concepts of *critical thinking*, *mental simulation*, *foresight*

and ***general metacognition***, also represented in Table 1, were considered pivotal to expert efficiency. As such, prompting principles that outline relevant cognitive principles can add value to the prompting framework under development presently.

Novices rarely engage in metacognition, and therefore do not tend to monitor, evaluate or regulate their problem-solving approach (An & Cao, 2014; Flavell, 1979; Roll et al., 2012). Therefore, novices are more likely to make unfounded assumptions and be unwilling to abandon non-productive strategies (Kim & Hannafin, 2011). This hinders learning and introduces decision errors that can erode the quality of problem-solving. In contrast, experts invest considerably more cognitive resources in metacognitive activity (Shanteau, 1992). Due to experts' propensity to consider more alternate solutions, and their ability to draw on domain-relevant knowledge and thinking strategies in order to alleviate cognitive load, experts are more predisposed (and better equipped) to engage in greater levels of critical thinking (e.g., Halpern, 1998; Helsdingen et al., 2010). In ill-structured problems experts often test their outputs through the use of mental simulation in order to ensure that their solution is adequate. Where appropriate, foresight may be used to assess whether the solution is likely to remain adequate given anticipated changes in the problem-solving environment (Heuer, 1999). Such processes aid in the evaluation of competing alternatives or when evaluating problem-solving effectiveness. Compared to novices, experts are better aware of and better able to learn from errors and will adjust their problem-solving approach accordingly (Ge & Land, 2004).

Developing expertise. Expertise is acquired by learning the basic domain knowledge and appropriate problem-solving procedures before engaging in extensive and varied practice whereby knowledge and strategy management improves and the frequency of errors decreases (e.g., Fitts & Posner, 1967). Problem-solving competence is further consolidated

via reflective and integrative metacognitive practices that provide feedback that aids in the identification of strengths and weaknesses in the problem-solving approach. Such metacognitive processes act to consolidate the learning of effective strategies and explore the mitigation of ineffective ones (Baartman & de Bruijn, 2011). There is further indication that adaptive expertise can be encouraged by the internalisation of generic metacognitive skills which engender learning in many problem-solving episodes or contexts (e.g., Eccles & Feltovich, 2008; Klein & Baxter, 2009; Roll et al., 2012). Therefore, developing learning support tools that elicit expert sensemaking and metacognitive processes in novices can support the acquisition of both domain-specific and generic problem-solving skills. The focus of the paper now turns to the utility and design of scaffolding as an instructional tool.

Scaffolding

The principle of scaffolding has developed around the notion of a ‘zone of proximal development’ (ZPD: Wood et al., 1976; Vygotsky, 1980). The ZPD represents the gap between an individual’s current level of knowledge and performance, and the level of performance that can be attained with appropriate support and assistance. As learning progresses and the ZPD diminishes, scaffolding is faded and eventually removed to support internalised learning and the development of independent skill (Sharma & Hannafin, 2007). Scaffolding content should encompass expert processes and instructional design principles (e.g., feedback, metacognition, appropriate cognitive load). However, its application can take various forms and the framework developed presently utilises a series of targeted questions or ‘prompts’ (Holden & Sinatra, 2014).

In addition to eliciting expert cognitive processes, a prompted scaffolding approach offers three main benefits to novices tackling ill-structured problems. Firstly, prompt sequencing can make explicit the procedural elements of problem-solving (Sharma &

Hannafin, 2007). In doing so prompts can accelerate the acquisition of procedural knowledge, i.e., knowledge of ‘how to go about solving a problem’ and can provide a structured sequence to organise sensemaking efforts (Weick et al., 2005). Thus prompts act to reduce uncertainty, promote ordered thought processes, and direct cognitive resources more efficiently among novice problem-solvers. Secondly, prompts generate explicit and actionable feedback which is typically hard to ascertain in complex, ill-structured contexts (Byun et al., 2014; Ge et al., 2005; Halpern, 1998; Kim & Hannafin, 2011; Sharma & Hannafin, 2007). Where feedback indicates effective performance, the knowledge generated from feedback can be consolidated or integrated into appropriate schemata. Where feedback indicates ineffective performance, prompts can be used to uncover and explore the causes of any faulty reasoning and strategies can be developed to mitigate future errors. A final but related 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 (Ge & Land, 2003; Roll et al., 2012; Vogel-Walcutt et al., 2009), that metacognitive skill can be taught via prompting (Coulson & Harvey, 2013; Vogel-Walcutt et al., 2009), and similarly, that metacognitive activity continues once scaffolding has been faded (Byun et al., 2014; Roll et al., 2012). Hence, prompting serves to equip problem-solvers with an internalised learning approach that can be exploited in other contexts (Holton & Clarke, 2006; Holton & Sinatra, 2014; Roll et al., 2012)

An important distinction can be made between the benefits of after-action, as opposed to within-action prompting (e.g., Schön, 1983; Eraut, 1994). Engaging with after-action prompts is a reflective activity aimed at improving awareness and knowledge of both the cognitive processes used and strategic judgments made. In contrast, within-action prompting evokes the monitoring and regulation of cognition whilst concurrently engaged in a problem-solving task. The utilisation of such prompts aids in teaching self-regulatory skill and is

indicative of growing competence within a domain, particularly once scaffolding has been faded as prompted principles become internalised. From a novice perspective, there are differing cognitive load considerations (Sweller, 1994) for each approach. Engaging with prompts within a problem-solving task will place additional demand on limited mental resources that may already be overwhelmed with the processing of task-relevant information. Therefore, within-action prompting may offer little or no advantage to the very inexperienced problem-solver. However, engaging with after-action prompts will allow a novice problem-solver to assess their problem-solving efficiency once cognitive load has eased. With deliberate practice, key cognitive principles will be assimilated into schemata that will automatically activate relevant knowledge and cognitive strategies in subsequent problem-solving episodes. This will serve to lighten the level of cognitive load experienced. At this point spare cognitive resources can be directed towards engaging with within-action prompts. Hence, the learning afforded by after-action reflection acts as a precursor and enabler to the development of self-regulatory skill (Berthold et al., 2012; Sitzmann & Ely, 2010).

In summary, prompts offer an advantageous way of scaffolding and improving problem-solving strategies and learning outcomes among novices in ill-structured contexts. Prompt content should be designed to target and elicit expert cognitive processes such as those related to sensemaking and metacognition, as outlined in previous sections and captured in Table 1. An adaptable method, whereby prompts can be tailored to support problems with varying degrees of structure offers a flexible instructional approach that can accommodate changes in problem structure as a result of ongoing and iterative sensemaking efforts (e.g., Restrepo & Christiaans, 2004). Finally, consideration should be given to the level of cognitive load experienced by novice problem-solvers, with initial focus on after-action prompts before transitioning to within-action prompts and eventual prompt removal.

The remainder of this paper outlines a prompting framework centred on these principles and discusses guidelines for its implementation and applications.

A prompting framework

The presently proposed prompting framework is outlined in Table 2. Aligned to sensemaking and metacognitive principles are prompts designed to support performance and enable learning in severely ill-structured problem-solving contexts. The prompting method may be tailored to problems with more structure simply by omitting cognitive processes that are not aligned to the relevant problem structure category, as depicted in Table 1. Table 2 also indicates how the proposed framework can be adapted for both after-action or within-action use. The list of after-action prompts is purposely more extensive than the list of within-action prompts. This is due in part to additional cognitive load considerations, as prompt processing requirements will compete with the processing requirements of the primary problem-solving task in within-action prompting. After-action prompting is not subject to the same processing competition, enabling the timely consideration of a set of more comprehensive prompts. A related justification for engaging with more after-action prompts takes into consideration the experience of novices and the resulting size of the ZPD. As the degree of learning that can be supported is greatest at the onset of learning, initial learning can be best supported and accelerated by engaging in more rigorous and extensive after-action prompting. The following section considers guidelines for applying the prompting framework effectively.

<<Insert Table 2 approximately here>>

Guidelines for framework implementation. There are a number of scaffolding principles that should, wherever possible, be implemented alongside the application of prompts. These are now outlined:

- Care should be taken to promote the benefits of prompts before the novice is exposed to them. Highlighted benefits should include the internalised learning approach that can be instilled and exploited in other contexts (Eccles & Feltovich, 2008; Klein & Baxter, 2009; Roll et al., 2012). Promoting the utility of the framework should act to encourage engagement with the prompts and may boost motivation to learn within practice opportunities.
- Novices may require additional support when first exposed to prompts. Likewise, additional support may be required when transitioning from engaging with after-action to within-action prompts. Modelling prompt engagement via worked examples should fulfil this purpose (Coulson & Harvey, 2013; Sharma & Hannafin, 2007).
- Novices should be made aware that prompts will be faded in order to more effectively manage expectations. The planned withdrawal of support should create an impetus for the novice to switch from relying on prompts towards acquiring the internalised learning approach and independent skill. Setting such expectations highlights that the novice is expected to take ownership of their own learning approach and can help in the latter adoption of self-regulatory processes.

Implications for technology-enhanced learning environments (TELEs). The generic prompting framework proposed presently has the potential to be assimilated into computerised learning materials. There is already some evidence indicating that prompting can be beneficial in simulated training environments (Berthold et al., 2012; Vogel-Walcutt et al., 2009). There are also researchers advocating the use of scaffolding prompts within cognitive tutoring systems (e.g., Roll et al., 2007) and other TELEs (for a more in-depth review, see Sharma & Hannafin, 2007). Modifications to the prompts developed presently may offer further utility to group cognition within TELEs. Here, the lines of cognitive

enquiry elicited by prompts can act as discussion points enabling the collective group understanding to improve individual problem-solving awareness.

Whilst confident that incorporating well-designed prompts into TELEs can lead to beneficial learning outcomes, the challenge remains as to how best to design the interface to ensure that the cognitive benefits of prompts are realised. Key human-computer interaction considerations such as visibility, usability, user control and the level of interaction (e.g., Sims et al., 2002) must be balanced. Other considerations concern the method of scaffolding delivery (research diaries, blogs, advance organisers etc.) and how best to assess learning outcomes and fade prompt delivery. As such, the present framework can be considered as a building block around which interface design options should be explored.

Prompt limitations. There are a number of limitations that could affect the utility of and engagement with prompts in TELEs. Prompts may be ignored or answered superficially (Byun et al., 2014). This may be especially problematic in distance-only learning environments where the level of perceived accountability is diminished. Whilst early promotion of the benefits of scaffolding may improve the level of engagement with prompts, consideration should be given to methods of capturing and auditing prompted responses in order to monitor engagement and increase the levels of perceived accountability. Another limiting factor is that certain prompts may only be relevant once some initial learning has taken place (Byun et al., 2014). Whilst the present prompting framework has been designed to be generic to all ill-structured domains, and the use of work examples and modelling to familiarise novices with prompting has been advocate, it may be that there will be a minimal number of practice trials before the novice is confident that they can respond to prompts appropriately. This minimal level may fluctuate between individuals and may be more apparent in ill-structured technical domains. Therefore, novices should be made aware that

mistakes offer valuable learning potential. They should also be assured that in ill-structured problem contexts there are no definitive correct answers and that attempting to engage with and answer 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 further limitation is that exhaustive and overly complex prompts may reduce motivation. Once again, such effects could be mitigated by promoting the utility of prompts and highlighting the gradual withdrawal of structured prompting as the novice becomes responsible for regulating their own generative learning episodes. A final limitation regarding the utility of the framework developed concerns the wording of prompts. As prompts were designed to be generic, it is likely that the wording may appear crude or clumsy in some contexts. It is envisioned that some of the prompts may need some small semantic adjustments in order to more closely align the prompts with the specific problem-solving context.

Conclusions

The present paper has synthesised the relevant problem-solving and expertise literature and drawn upon scaffolding and instructional design principles in order to develop and outline an adaptable prompting framework for eliciting sensemaking and metacognitive activities in novices. The framework was developed in such a fashion so as to be generically applicable to a wide-range of ill-structured tasks in a variety of domains. In conjunction with the framework, some guidelines concerning its implementation have been proposed along with implications for TELEs.

A primary focus for future research will be to test and refine the method proposed presently to assess its utility for supporting the cognitive problem-solving processes of novices. Such an undertaking would require examining the performance of novices with

differing levels of experience whilst tackling problems of varying degrees of structure within differing ill-structured contexts. Secondly, the development of assessment criteria would allow some quantification of the benefits of engaging with prompting. Assessment criteria would also provide some insight as to when the nature of scaffolding should be adapted or faded.

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