Framework to Facilitate Metacognitive Strategy Development in Computer-mediated Instruction: A Design and Development Study

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ABSTRACT

This study develops a computer-based interactive content design framework to guide the design of metacognitive scaffolds in ill-structured problem-solving instruction. It adopts Type II design and development research approach to create a comprehensive and generalizable instructional design framework. The framework was composed by synthesizing research and practical literature, and then evaluated by experts in related fields. The completed framework includes metacognitive strategies, instructional design strategies, interactive media types, question prompts, and feedback. Instructional designers, instructors, and other key stakeholders could follow the guidelines proposed in this framework to create metacognitive-based ill-structured problem-solving instruction using e-Learning authoring tools. On one hand, this study bridges the gap between theory and practice; on the other hand, it adds to literature in media research with focusing on utilizing various media types to create effective learning materials

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GENERAL AUDIENCE ABSTRACT

Metacognition is called thinking of thinking, and it has been acknowledged as key to solving everyday problems. Learners can be trained to obtain metacognitive skills to become efficient problem solvers. In this study, I propose a framework to guide teachers and designers to add computer-based interactive activities in problem-solving instruction. When a learner is taking a computer-based lesson by him/herself, those interactive activities can help them develop metacognitive skills, including monitor, evaluate, and reflect on their thinking and learning. For instance, a chatbot can be integrated into a computer-based learning environment to answer students' questions and guide them throughout the learning process. Overall, this study makes several contributions. On one hand, the design guidelines proposed in this framework can be used to create instruction in a variety of disciplines. One the other hand, it enriches the literature on studying the effective use of media when designing computer-based curriculum.

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Dedication

To my parents, family, and friends.

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CHAPTER 1: INTRODUCTION

Introduction

Problem solving is an essential skill for success in the 21st century (Belland, 2013; Mishra & Kereluik, 2011). It has been studied extensively in mathematics (Jonassen, 2011; Lester, 1994; Wilson, Fernandez, & Hadaway, 1993), engineering (Pappas, 2002; Pappas & Pappas, 2003), and online information searching (Lazonder & Rouet, 2008; Walraven, Brand-Gruwel, & Boshuizen, 2008). Metacognition has been regarded as a key component in problem-solving (Cardelle-Elawar, 1992; Lin, Hmelo, Kinzer, and Secules, 1999; Redding, 1990; Shen & Liu, 2011; Tarricone, 2011), especially in solving ill-structured problems (Ge & Land, 2003; Jonassen, 2000; Shin, Jonassen, & McGee, 2003). However, there is also a lack of instructional materials that teach metacognition in solving ill-structured problems. Jonassen (2000, 2011) suggested more attention should be given to the study of problem solving in the field of instructional design.

The term metacognition was first introduced by John Flavell in the 1970s, and it is also called second-order cognition and cognition of cognition (Flavell, 1987; Papaleontiou-louca, 2003; Tarricone, 2011) as “meta” means beyond. More specifically, it refers to the knowledge, awareness and regulation of cognitive processes (Akturk & Sahin, 2011; Brown, 1987; Flavell, 1979, 1987; Livingstone, 2003; Tarricone, 2011; Zimmerman, 2002). Although other renowned scholars did not name it metacognition, they emphasized the important role that metacognition plays on academic performance and intelligence growth of the learner. Vygotsky (1986) described metacognitive process as “the consciousness of being conscious” (p.170), and Piaget (1952) regarded reflection as critical metacognitive process that is key to the development of intelligence. There are three major components of metacognition, which are metacognitive knowledge, metacognitive experience, and metacognitive skills (Efklides, 2008). Metacognitive knowledge is the learner's stored world knowledge (Flavell, 1979), knowledge about oneself and cognitive tasks (Krathwohl, 2002; Ku & Ho, 2010). Metacognitive knowledge is composed of three layers of knowledge, which are declarative knowledge (knowing what), procedure knowledge (knowing how), and conditional knowledge (knowing when and why) (Schmitt & Newby, 1986; Schraw & Dennison, 1994). Metacognitive experience refers to the feeling and judgment towards completing tasks (Efklides, 2008; Flavell, 1979). For instance, learners may experience anxiety if they are not confident in completing tasks. Metacognitive skills are also called metacognitive strategies (Efklides, 2008, 2014; Veenman & Elshout, 1999) that include planning, monitoring and evaluating thinking processes (Akturk & Sahin, 2011; Gordon, 1996; Ku & Ho, 2010).

In addition to problem solving, studies show that metacognition is also related to critical thinking skills (Halpern, 1998; Ku & Ho, 2010; Magno, 2010) and academic performance (Joseph, 2009; Narang & Saini, 2013; Schraw & Dennison, 1994; Shen & Liu, 2011). Successful learners obtain better metacognitive strategies than low achievers (Brown, Hedberg, & Harper 1994; Cardelle-Elawar, 1992; Kruger & Dunning, 1999; Schmitt & Newby, 1986) because they are more aware and skillful in planning, monitoring and controlling their thinking processes (Joseph, 2009; Narang & Saini, 2013; Schraw & Dennison, 1994). Whereas novice learners tend to overestimate their abilities due to the failure in monitoring and controlling their cognitive processes (Kruger & Dunning, 1999). Numerous studies claimed that learners could become more aware of and better at regulating their thinking processes by adopting appropriate metacognitive strategies that lead to improved performance (Livingston, 2003; Schmitt & Newby, 1986; Shen & Liu, 2011) and transfer of skills (Brown et al., 1994; Redding, 1990; Shen & Liu, 2011).

Need for the Study

Abundant computer-based learning environments have been created to facilitate the development of metacognitive skills, and those environments include Betty's Brain (Biswas et al., 2005; Leelawong & Biswas, 2008) and MetaTutor (Azevedo, Witherspoon, Chauncey, Burkett, & Fike, 2009; Azevedo, Johnson, Chauncey, & Burkett, 2010). However, there seems to be a lack of computer-based learning materials that were created to facilitate metacognitive development in solving ill-structured problems. Integrating metacognitive activities in computer-based problem-solving instruction to teach and train metacognitive strategies not only enables learners to solve problems, but also provides them with interactive and engaging learning experiences.

Those metacognitive activities or scaffolds could be created with utilizing the interactive features in e-Learning authoring programs. In the past decades, numerous media comparison studies concluded no difference in learning outcomes when using different technologies to deliver instruction. Rather than spending efforts on proving one media is better than the other, a few researchers believe that it is worthwhile to focus on the utilization of functional attributes into creating effective instruction (Head, Lockee, & Oliver, 2002; Sims, 1997). Therefore, further investigation into media attributes is needed to design and develop instructional activities that generate more meaningful and effective learning experiences. Both the affordances and constraints of different media should be considered when designing learning environments (Collins, Neville, & Bielaczyc, 2000).

Currently, a large number of computer-based learning materials are produced using e-Learning authoring tools, including Articulate Storyline, Adobe Captivate, and Camtasia. Implementing various features of those tools in creating effective e-Learning instruction could improve the quality of computer-based instruction as well as the learner's learning experience. Functional attributes of those e-Learning authoring tools include multiple choice questions, shorts answers, and auto-grading, which can be used to develop metacognitive scaffolds, such as question prompts. By taking metacognitive-based e-Learning instruction, learners acquire metacognitive skills to plan, control and monitor their learning processes.

However, the literature is sparse in studying the application of interactive media attributes in creating computer-based instruction to support metacognitive development. In consideration of the critical role that metacognition plays in enhancing learner's problem-solving skills, there is a need to produce high quality computer-based learning materials to teach metacognitive skills to an increasing number of online learners (Brown et al., 1994; Shen & Liu, 2011).

An instructional framework that guides the design of computer-based metacognitive materials would be extremely beneficial to instructional designers, instructors and practitioners to create problem-solving instruction. In line with these goals, this study is conducted to design such guidelines that incorporate literature from instructional design, interaction design, multimedia design, message design, human-computer interaction (HCI) and communication fields. For instance, Kim, Yoon, Whang, Tversky and Morrison (2007) studied the effect of animation on comprehension and interest; Garris, Ahlers and Driskell (2002) investigated the features and user experience of instructional games; Sundar et al. (2010) studied various types of user-interactions, including click, drag, flip, and mouse-over, and later on, Sundar, Bellur, Oh, Xu and Jia (2014) added sliding, zooming, hovering, dragging techniques in their user studies of web content; Mayer (2009) also highlighted different media attributes, including arrows, pointing, and graying out, which were used in multimedia instructional design. By examining various interactive features of e-Learning authoring applications, this design framework employs a bottom-up approach that starts from exploring media attributes at the micro-level to design instructional activities at the macro-level.

Purpose of the Study

The purpose of this study is to design an interactive content design framework that serves as guidelines for creating standalone computer-based interactive learning materials to teach and train metacognitive strategies using e-Learning authoring tools. By embedding metacognitive scaffolds in the self-paced instruction, learners are trained to monitor and control their thinking process efficiently during problem solving process. This framework consists of several components, including metacognitive strategies, instructional strategies or activities and functional attributes of e-Learning authoring tools. This framework is built upon research and practical literature, meanwhile connects theory with practice. It serves two primary purposes. On one hand, it could be used as guidelines by instructional designers, instructors, and trainers to design computer-based learning materials that aim to teach, train, and improve learners' metacognitive strategies. On the other hand, this framework highlights critical metacognitive strategies and their corresponding instructional activities, which could be used by developers and practitioners as a reference to develop metacognitive learning tools and environments.

Benefits of the Study

This study contributes to the advancement of research and practice in the field of instructional design and technology by integrating media attributes into the design of computer-based interactive content to teach and train metacognitive strategies. Firstly, it fulfills the research promises of utilizing the functional attributes of media to design instruction, which may pave a new path for media research instead of reusing the old approach of comparing the effectiveness of different media. Secondly, it adds to the literature of implementing metacognitive components into the design of computer-based learning materials by proposing a framework to guide such design. Thirdly, it has the potential to bridge the gap between theory and practice as this design framework derives from the concept of metacognition, constructivism theory, and interaction and multimedia design practices. Fourthly, it contributes to the interdisciplinary research and practice as it incorporates concepts and empirical research findings from various disciplines, including instructional design, interaction design and HCI. Fifthly, the metacognitive strategies presented in the guidelines are not domain specific, which can be applied into the design of interactive instruction in various disciplines (Shen & Liu, 2011; Pintrich, 2002). This framework contains a variety of question prompts for instructional designers and instructors to implement when creating computer-mediated instruction. Furthermore, this framework could also be used to guide the design of computer-based materials to teach and train metacognitive strategies in corporate settings.

Limitations of the Study

This is an exploratory study for creating a design and development model that guides the design of interactive content to teach and train metacognitive strategies. However, there are limitations to this study. On one hand, there is a scarcity of studies on investigating the design and development of interactive content to facilitate metacognitive development. On the other hand, this model will only be evaluated by a few experts due to the scope and timeline of this study. It may work from the theoretical perspective but needs further validation through the use and application of this model in authentic learning and working environments. Therefore, there are potential areas for improvement in the proposed framework. Additionally, this design framework is proposed based on the interactive attributes of e-Learning authoring programs, it may be not generally applied in the design of interactive content using other computer-based programs or environments.

CHAPTER 2: LITERATURE REVIEW

Introduction

According to Jonassen (2000, 2004), problems vary in structuredness, complexity, and abstractness. He studied problem solving in a wide range of contexts and developed a typology of problems solving that summarizes problems into 11 categories. Those categories include (a) logical, (b) algorithmic, (c) story, (d) rule-using, (e) decision making, (f) troubleshooting, (g) diagnosis-solution, (h) strategic performance, (i) case analysis, (j) design, and (k) dilemma (Jonassen, 2000). The problems shift from well-structured to ill-structured from category a to k. Well-structured problems are usually textbook math and science problems, whereas ill-structured problem occur in daily life and workplace settings (Jonassen, 2000; Jonassen, Strobel, & Lee, 2006).

In comparison with well-structured problems, ill-structured problems are situated and more complex (Jonassen, 1997, 2000). To solve an ill-structured problem, it requires knowledge from various content areas, and the outcome is unpredictable (Jonassen, 1997, 2000). Well-structured problem-solving skills acquired from one context can be applied in similar environments, whereas ill-structured problem-solving skills are capable of far transfer that allows the learner to apply those skills in new situations (Jonassen, 2000; Foshay & Kirkley, 2003). The importance of ill-structured problem solving is highlighted in education (Bulu & Pedersen, 2010; Foshay & Kirkley, 2003), and it is crucial to teach and train learners of the ill-structured problem-solving skills so that they will become proficient problem solvers in workplace and daily life.

Scholars agree that metacognition is key to solving ill-structured problems (Lin et al., 1999; Jonassen, 2000), and it can be learned via strategy training (Ge & Land, 2003;

Jonassen, 2011). Ge and Land (2003) and Bulu and Pedersen (2010) stated that scaffolding strategies could be utilized to support metacognitive development during ill-structured problem-solving process. Scaffolding refers to supports that are provided to learners to complete tasks that are beyond their capabilities and then fades away when no longer needed (Collins, 2006; Merrill, 2002). Implementing scaffolds in learning process could help learners bridge the gap between their current abilities and aimed goals (Bulu & Pedersen, 2010). Metacognitive scaffolds can be created using the interactive media types in e-Learning authoring tools and implemented in computer-based ill-structured problem-solving instruction.

With the rapid development and deployment of computer-based learning materials, many learners have taken online or computer-based instruction using their personal devices, including computer and mobile phones. However, a considerable number of instructional guides for creating the computer-based learning materials are purely practice-based without theoretical supports. Additionally, there seems to be a lack of computer-based instruction that aims to teach, or train metacognitive skills given the important role that metacognition plays in solving ill-structured problems. This study presents a design framework that guides the design of computer-based metacognitive scaffolds in solving ill-structured problems based on existing research and practical literature from relevant areas.

Theoretical Foundations

This study reviews literature on empirical research, theoretical papers, and practices in the fields of education, instructional design, interaction design, message design, HCI, and communication. It presents the definition, origins, and multiple facets of metacognition, introduces regulation of cognition concept and its implication on metacognitive strategies, describes the constructivism-based learning environment, and elaborates on key principles of designing interactive content and learning environment (e.g. interface and message).

Definition of Metacognition

This term "metacognition" was introduced by John Flavell in the 1970s, and it has been studied and researched extensively since then. This concept derives from the terminology "consciousness" that appears in Vygotsky and Skinner's Work (Vygotsky, 1986; Skinner, 1974). Skinner (1974) viewed consciousness as awareness by which the learner is reflective of his or her own actions. Upon receiving stimulus (new information), the learner reacts by monitoring and controlling his or her activities when processing new information. Similarly, Vygotsky (1986) described consciousness as the awareness of cognitive activities. He also highlighted that words and signs are effective tools to develop reflective abilities in acquiring scientific concepts.

Flavell (1976) defined metacognition as monitoring, regulation and orchestration of cognitive processes, and he believed that teaching children and adults metacognitive knowledge and skills could help them make wise decisions not only in learning situations, but also in various life situations. It is labeled as the second-order cognition and cognition of cognition (Flavell, 1987; Papaleontiou-louca, 2003). The definition of metacognition evolved over time, and it has been interpreted slightly different by various scholars. Brown (1987) viewed it as the knowledge and control of cognition, Jones, Farquhar and Surry (1995) defined it the management of thought processes, Zimmerman (2002) regarded it as the knowledge and awareness of thinking process, and Efklides

(2008) and Tarricone (2011) interpreted it as knowledge, awareness, monitor, and control of cognitive processes. It concerns not only about cognition, but also affective reactions, including emotion and motivation (Flavell, 1979; Papaleontiou-louca, 2003).

There are multiple facets of metacognition: a). It consists of three dimensions that are metacognitive knowledge, metacognitive experiences, and metacognitive strategies (Efklides, 2008). b). Regulation of cognition is an essential component of metacognition, and self-regulatory skills are regarded as metacognitive strategies. c). Monitoring and control are fundamental self-regulation procedures, which serve as the connections between cognition and metacognition (Efklides, 2008; Tarricone, 2011). d). Metacognition concerns the management and regulation of cognition as well as affects and motivation aspects. Metacognition is not only studied at the individual level, but also group level (Efklides, 2008).

Metacognitive Knowledge

Metacognitive knowledge is the fundamental component of metacognition, which shapes metacognitive experience and strategies. It is considered as the knowledge about oneself, task and strategies (Krathwohl, 2002; Pintrich, 2000) and consists of three variables that are person variable, task variable, and strategy variable (Flavell, 1979). Person variable concerns the knowledge about individual differences and cognition; task variable considers the task difficulty and quantity and quality of available information to complete the task; strategy variable regards choosing and using appropriate strategies to achieve performance goals (Flavell, 1979; Pintrich, 2000). Metacognitive knowledge can be expanded and updated via participating in metacognitive activities (Efklides, 2008).

Three types of knowledge are regarded as metacognitive knowledge, which are declarative knowledge, procedure knowledge and conditional knowledge (Schmitt & Newby,1986; Schraw & Dennison, 1994). Declarative knowledge is defined as knowing what, and it is viewed as stable knowledge (Pintrich, 2000; Tarricone, 2011), including knowing about oneself, tasks, and strategies (e.g. a person is aware that he or she is good at math rather than physics), familiar with different types of tasks (e.g. problem solving, critical thinking, and memorization) and cognitive strategies (e.g. rehearsal, mnemonics, and elaboration). Procedure knowledge is described as knowing how to use appropriate strategies (Pintrich, 2000; Schraw & Dennison, 1994; Tarricone, 2011). For instance, in order to comprehend and memorize a new concept, the learner can use encoding strategy to construct meaningful understanding of the new information based on one's knowledge and past experiences, as well as adopt repetition and rehearsal strategies for practice. Conditional knowledge is regarded as knowing when and why to certain cognitive strategies (Pintrich, 2000; Schraw & Dennison, 1994). It is useful for problem solving and transfer of skills and knowledge.

Metacognitive Experience

Metacognitive experiences are defined as the awareness of cognitive and affective experiences, and it is informed by metacognitive knowledge (Efklides, 2009; Flavell, 1979). It refers to the feelings and judgments of cognition (Efklides, 2008, 2014), which include Ease of Learning (EOL), Judgment of Learning (JOL), and Feeling of Knowing (FOK). Metacognitive experience can affect one's emotion and motivation. For instance, the feeling of mastering a new skill can lead to satisfaction and accomplishment. In contrast, negative effects (e.g. disappointment or dismay) can be evoked when the learner experiences the feeling of difficulty or not meeting preset goals. Being aware of one's cognitive process as well as emotional state, the learner can adjust the goals, strategies and emotions effectively (Paris & Winograd, 1990).

Ease of learning. EOL judgment takes place prior to the acquisition of new knowledge (Nelson & Narens, 1994). It involves inferences a learner makes regarding how easy or difficult to learn a new concept or knowledge and how much time is required to master a certain skill (Nelson & Narens, 1994; Pintrich, 2000; Schwartz, 1994; Winne, 1996). EOL occurs at the initial phase of metacognitive process, which helps the learner to estimate the task difficulty and allocate appropriate amount of time to acquire new knowledge or skills.

Feeling of knowing. FOK occurs during or after a learning session (Nelson & Narens, 1994). Schwartz (1994) defined it as the judgment of retrieving information. FOL has been studied in retention tests (e.g. recall items) to diagnose whether a learner remembers an item or not (Nelson & Narens, 1994; Pintrich, 2000). According to Pintrich (2000), FOK happens when a learner feels that he or she knows the concept or topic but cannot recall at that moment. This provides implication for adopting appropriate strategies, including providing cues for the learner to recall the concept, skill, or make connections between similar concepts and topics.

Judgment of learning. JOL focuses on monitoring the learning processes, including pace of learning, readiness for evaluation, and prediction of learning outcomes (Efklides, 2008; Pintrich, 2000). It occurs during or after the learning session (Nelson & Narens, 1994). JOL is critical in metacognitive processes as it emphasizes on the reflection of learning process and prediction of learning outcomes. By monitoring the cognitive process, the learner is aware of the progress that has been made and able to assess their learning outcome and readiness for taking an exam. It is through metacognitive awareness that learners can further plan and control cognitive activities (Schraw & Dennison, 1994).

Metacognitive Strategies

Metacognitive strategies are also called metacognitive skills, thinking skills (Efklides, 2008, 2014; Georghiades, 2004), or self-regulation skills (Joseph, 2009; Tarricone, 2011). It refers to the use of strategies to control and monitor cognitive processes (Brown et al., 1994; Efklides, 2008; Flavell, 1987) to achieve learning goals (Livingston, 2003). Metacognitive strategies are metacognition in action that controls cognitive activities. It manages cognition as learners need to make a plan prior to working on a task, select or alter cognitive strategies during task execution phase, and make revisions afterwards (Paris & Winograd, 1990). Thus, it occurs before, during and after cognitive activities (Akturk & Sahin, 2011). Metacognitive strategies are not domain specific but can be applied in various domains (Shen & Liu, 2011).

Skillfulness in metacognitive strategies leads to awareness of cognitive processes, improved learning outcomes and transfer of skills in other situations (Cardelle-Elawar, 1992; Livingston, 2003; Narang & Saini, 2013; Schmitt & Newby, 1986). Studies show that low performers lacked metacognitive skills, and they failed to keep track of their progress that often resulted in overestimating their performance (Kruger & Dunning, 1999). However, metacognitive strategies can be taught to help student monitor, control and reflect on their learning processes (Shen & Liu, 2011). Instructional activities, including taking notes during the learning process (Makany, Kemp, & Dror, 2009) and creating electronic portfolio for reflection (Zellers & Mudrey, 2007) have been implemented to enhance metacognition.

Metacognitive strategies can be carried out in a linear fashion that consists of setting learning goals and planning learning activities, monitoring cognitive processes, and reacting by adjusting, continuing or terminating the use of current cognitive strategies. Existing literature on metacognitive strategies can be summarized into two levels, which are macro-level and micro-level. Macro-level metacognitive strategies comprise of management and control of cognitive strategies at a higher level. Whereas micro-level metacognitive strategies are small scale, specific and executable strategies, including setting goals and monitoring activities.

Regulation of Cognition

Metacognitive strategies have been used interchangeably with regulation of cognition (Ku & Ho, 2010; Sperling, Howard, Staley, & DuBois, 2004). The existing literature and research on regulation of cognition provides implication on the study of metacognitive strategies. Monitoring and control are essential self-regulation processes (Tarricone, 2011) and regarded as crucial metacognitive strategies. Flavell (1979) stated that monitoring occurred through the interaction among metacognitive knowledge, metacognitive experiences, goals and strategies. Kirsh (2005) used the cooking metaphor to demonstrate the importance of monitoring and control processes on affecting task performance. For instance, cooks use clocks, timers and temperature indicators to monitor the cooking process and adjust the time and temperature accordingly to make sure that the food is cooked properly. EOL, JOL, and FOK are indicators of metacognitive awareness that are monitored during the regulation processes (Nelson & Narens, 1994; Pintrich, 2000).

Nelson and Narens (1994) stated that information is exchanged between two levels within the metacognitive system, which are meta-level and object-level. Cognitive activities occur at the object-level, whereas metacognitive activities take place at the meta-level. Information processing and exchange between these two levels are managed through the executive monitoring and control activities (Nelson & Narens, 1994). This can be explained using the metaphor of employer-employee relationship. The boss is at the meta-level who monitors the working process of his or her subordinates who are at the object-level. By monitoring the work process and task performance at the object-level, the boss can control those activities by giving further orders, such as approving the completion of a task or providing feedback for revision.

Efklides (2008) claimed that the object level concerns both cognition and affect dimensions. According to Efklides (2008), the object-level contains non-conscious monitoring and control of cognitive activities, and Fernandez-Duque, Baird and Posner (2000) stated that schema is the fundamental element exists in the object-level. Schemas are organized mental structures consist of rules and concepts to understand and interpret the world (Shoari & Farrokhi, 2017; Widmayer, 2007). Whereas, consciousness and awareness of the cognition occurs at the meta-level. By monitoring the cognitive process and affective reactions at the object-level, the meta-level is informed by the bottom-up information, and in return regulates the object-level activities (Fernandez-Duque et al., 2000). This generates a feedback loop between the object-level and meta-level, and learners regulate this process constantly.

Self-regulated learning theory proposes that learners should take active roles to construct knowledge by tracking and reflecting on their cognitive processes instead of receiving knowledge passively (Pintrich, 2000). A number of self-regulated models were created that delineate those self-regulation processes. Winne and Hadwin (1998) developed a four-stage self-regulated learning model. At stage 1, learners need to define a task, and then set goals and plan strategies that are used to complete the task in stage 2. At stage 3, they will execute the plan and tactics, and finally monitor and reflect on the learning processes at the last stage. Similarly, Pintrich (2000) created a four-phase self-regulated learning model, which includes forethought, planning and activation phase; monitoring phase; control phase; reaction and reflection phase. This model not only focuses on managing the cognitive but also psychological processes, including motivation and affective components. Later, Zimmerman and Campillo (2003) proposed a three-phase self-regulation model where they combined the monitor and control phases in Pintrich's model and named it as performance phase. Thus, the three phases are forethought phase, performance phase, and self-reflection phase.

Many computer-based learning tools have been developed to facilitate self-regulated learning. For instance, a research team at the Vanderbilt University developed a computer-based system, called Betty's brain, to facilitate self-regulated learning processes. Within that system, a learner teaches Betty (virtual agent) a science phenomenon, and Betty constructs a concept map that shows the main concepts and relationships between them. Afterwards, Betty answers quiz questions using information generated from the concept map (Biswas et al., 2005; Leelawong & Biswas, 2008). The performance on the quiz provides feedback for learners to reflect on their learning process, which allows them to modify the concept map to improve their performances. Another popular self-regulatory application is MetaTutor that supports and coaches a variety of self-regulatory skills, including goal setting, metacognitive monitoring and evaluation of learning outcomes (Azevedo et al., 2009; Azevedo et al., 2010; Azevedo et al., 2013).

The development of computer-based learning environment, including Betty's Brain and MetaTutor, provides implication on the creation of computer-based learning materials to teach and train metacognitive strategies. Those computer-based learning environments support learners in taking active roles in controlling and monitoring their thinking processes as well as constructing new knowledge. The design of those computer-based learning environments derives from constructivism theory that emphasizes active learning.

Constructivism

Constructivism theory acknowledges that new knowledge is generated through interaction between input information, learner's previous knowledge and experience, as well as contextual tools (Garrison, 1993; Papaleontiou-louca, 2003). The historical root of constructivism can be traced back to Piaget's intellectual development model (1952), which contains two crucial mental processes: assimilation and accommodation. Assimilation happens when the learner uses existing schemas to process new information, and the new information can either be a new event or situation. For instance, people behave differently at various occasions, which are guided by their mental schemas generated through past experience and knowledge. A person can jump, shout, and cheer at a sports venue, which are not considered as appropriate behaviors during a business meeting. Accommodation occurs when conflicts exist between new information and the learner's existing mental schemas, which results in either the modification of old schemas or the formation of new schemas. Assimilation and accommodation are critical cognitive processes for knowledge building (Bodner, 1986; Chermack & Van Der Merwe, 2003).

Constructivists view learning occurs through the interaction between the learner and its environment (Rieber, 1992). In a computer-based learning environment, the functional attributes of technology could be used to create metacognitive scaffolds to support learner during their learning process (Gordon, 1996; Papaleontiou-louca, 2003). For instance, question prompts can be created that allow learners to reflect on their learning process. Information can also be presented in various multimedia formats, including audio and video. Learners incorporate information from internal environment (i.e. schema) as well as external environment to construct knowledge, goals and strategies (Azevedo, 2005; Driscoll, 2005; Pintrich, 2000). Metacognitive scaffolds can be created to facilitate the assimilation and accommodation processes. Different from traditional instructor-led learning, constructivism computer-based instruction is learner-centered that allows learners to take control of their learning process with the facilitation of technologies (Duffy & Cunningham, 2001). Interactive multimedia plays an import role in constructing learner-centered environment (Gordon, 1996; Kirsh, 2005). The interaction between the learner and content is enabled by the interactive features in e-Learning programs. For instance, learners could click on the next button to go to the next topic and receive instant feedback when they respond to a question in an e-Learning course.

Learner-Content Interaction

Learner-content interaction is fundamental in computer-based learning environment, and it becomes a major approach to acquire new knowledge in distance education (Herman & Mustea, 2016; Xiao, 2017). In traditional education, knowledge is delivered by the teacher, which is typically one-way communication. There are fewer opportunities for one-on-one communication between the teacher and student during lectures, let alone providing feedback for each student. However, with the design and development of interactive content, individual-based instruction can be offered to learners. In computer-based learning environment, content is converted into digital formats (e.g. audio, video and animation), and then uploaded into a learning management system where learners can access those materials via their digital devices regardless of time and location. In recent years, it becomes a trend to design interactive content that improves learner satisfaction (Kuo, Walker, Belland, & Schroder, 2013) and enhances information comprehension (Weller, 1988). Learner-technology interaction connects the learner with content (Zimmerman, 2012), and it is process-oriented. Whereas learner-content interaction is both process and goal-oriented.

Interactivity. Interactivity is an inherent attribute of computer-based learning tools (Domagk, Schwartz, & Plass, 2010; Milheim, 1996; Sundar, 2004), which fosters active learning by allowing the learner to control, manipulate and navigate through the digitalized learning materials (Moreno & Mayer, 2007). Although interactivity and interaction have been used interchangeably (Wagner, 1997), differences exist between these two terms. Interaction is a broader concept that refers to various types of two-way communication, including learner-learner interaction, learner-teacher interaction, learner-content interaction, and learner-technology interaction. In contrast, interactivity mainly emphasizes on learner-technology interaction. Sundar, Jia, Waddell and Huang (2015) described interactivity as the opportunities the interface enabled for a user to communicate with others. According to Ha and James (1998), the playfulness and availability of choice are two critical features of interactivity that could enhance user satisfaction. Playfulness is achieved through the interaction between the user and computer interface, for instance, the click on an icon or image on the computer interface with receiving instant feedback could lead to improved learner interest and motivation.

Interactive Instruction

Interactive instruction has been designed with utilizing the functional interactivity attributes of web-based applications, and it has several distinguishing features. Firstly, it allows the learner to control the pace and sequence of the instruction, which can reduce anxiety and increase motivation (Domagk et al., 2010; Weller, 1988). Secondly, it generates an interaction loop between learner and content. Typically, the technology triggers the communication by showing the learner a question on the screen, the learner responds by either clicking on a button or typing in an answer, and then feedback is provided to the learner based on learner input (Evans & Gibbons, 2007; Hazen, 1985). Thirdly, it enhances the engagement between learner and content, which evokes active learning (Evans & Gibbons, 2007). Overall, interactive instruction provides learner with personalized, adaptive and engaging learning experiences.

There are four different types of interactive instructional design methods, including reactive, coactive, proactive and transactive (Rhodes & Azbell, 1985). Reactive design of instruction allows the user with limited control of the instruction, and the sequence of instruction and feedback from the program is predetermined (Milheim, 1996). Coactive design of the instruction empowers the learners with extended control of the pace and sequence of the instruction, it is more personalized instruction in comparison to reactive design of instruction. Proactive design is a more advanced form of personalized instruction, and it emphasizes on exploratory study where learners can choose what to learn and how to learn it. Transactive design of instruction enables the learner to define and solve problems using different media sources, and it also enables collaborative learning by taking feedback from experts and peers in addition to the computer.

Based on the learning goals, either an individual design method (e.g. reactive, coactive, proactive, transactive) or a combination of those methods can be implemented to design the instruction using interactive multimedia programs. Those interactive multimedia applications can be used effectively to create learner-centered content and environment that prompt learners to become aware of the learning processes (Gordon, 1996).

E-Learning Authoring Tools

E-Learning authoring application is one type of interactive multimedia programs that are used to produce computer-based learning content by manipulating and organizing a variety of multimedia elements in the applications (Haghshenas, Khademi, & Kabir, 2012; Paulsen, 2002). Those multimedia components contain different formats of interactivity, including button, textbox, and multiple-choice questions. Some of the most popular authoring tools are Articulate Storyline, Adobe Captive, and GLO Maker (Haghshenas et al., 2012). No programming skills are required to use those authoring applications; thus, the tools have been widely used by practitioners to produce e-Learning content. Materials produced using those e-Learning authoring tools are cost effective since the content are reusable (Specht, 2012). The interactive learning content design framework proposed using e-Learning tools in this study adopts the coactive and proactive design methods.

Instructional design models and principles have been used to guide the design of e-Learning and training materials. For instance, the ADDIE model is utilized to guide the creation of e-Learning content, which include the Analysis, Design, Development, Implement and Evaluation phases (Branch, 2009; Driscoll, 2010). Additionally, Gagne's nine events of instruction has been applied extensively to sequence the instruction (Hirumi, 2002), which include 1) Gain attention, 2) Inform learner of objectives, 3) Stimulate recall of prior knowledge, 4) Present content, 5) Provide learning guidance, 6) Elicit performance, 7) Provide feedback, 8) Assess performance, and 9) Enhance retention and transfer (Gagne, 1985; Gagne, Briggs, & Wager, 1992).

In consideration of the rapid adoption of new media and technologies in designing instruction, Richey and Morrison (2010) advocated for developing new theory and models to guide the design of instructional practices. Instructional framework is an inherent part of an instructional design model that "should contain enough detail about the process to establish guidelines for managing the people, places, and things that will interact with each other" (Branch & Dousay, 2015, p.25). The proposed framework in this study will provide details on designing instructional events that involve people, context and facilitated media. However, research and practice in the field of instructional design neglected the role emotion and motivation play in learning and performance as emotion could affect cognitive processes and strategies, decision-making and motivation

(Kim & Pekrun, 2014). Kim and Pekrun (2014) suggested developing a design framework that highlights the regulation of emotion and the activation of positive emotions. Thus, the framework presented in this study not only focuses on delineating the process of creating instructional events but also concerns the emotion and motivation aspects of the learner to obtain certain metacognitive strategies.

Jones et al. (1995) viewed metacognition as an advanced form of cognition that manages other cognitive strategies. To foster active learning and cognitive processes, several fundamental principles for interface and content design have been identified from the literature and included in the framework. Instruction that is created following the principles aims to create meaningful learner-content and learner-interface interactions with utilizing the interactive features of e-Learning authoring tools. Those principles are: instruction should allow learner control, obtain the browsing and navigation structure, and provide timely feedback. Principles on designing screen and message are also important components of the framework.

- Learner control. Allowing the learner to control the pace and sequence of instruction is a fundamental attribute of individualized instruction. Self-paced instruction allows the learner to work on his or her own pace and enables frequent interaction between the learner and program (Lockee, Moore, & Burton, 2004). The learner feels empowered and motivated when he or she has the control over learning process (Hazen, 1985; Weller, 1988), which also helps reduce anxiety (Weller, 1988). The media elements utilized within a computer-based learning program for pace control include forward, backward, and pause buttons. The control of learning sequence allows the learner to choose the order of receiving instruction using menus and table, as well as the type of media (e.g. text, audio, and video) to deliver instruction.

- Browsing/Navigation Structure. A computer-based learning program needs to obtain a clear navigation structure, which enables the learner to know where he or she is in the program. Menus, tables and maps could be used to present an overview and main topics of the content (Gavora & Hannafin, 1993; Hannafin, 1989; Jones et al., 1995; Weller, 1988). Additionally, when the learner browses through the learning content, important concepts should be emphasized using visual cues to draw learner's attention, including using words of a different color and highlighting with lines and boxes (Hazen, 1985).
- Timely Feedback. Questions presented in a computer-based learning program allow the learner to reflect on his or her learning processes (Hazen, 1985; Weller, 1988). Evaluating learner's responses and providing timely feedback are critical elements of interactive content (Jones et al., 1995; Milheim, 1996; Weller, 1988). According to Hazen (1985) and Weller (1988), there are three types of feedback, including confirmational feedback, motivational feedback, and instructional feedback. Confirmation feedback is given to confirm whether the answer is right or wrong (e.g. yes/no), motivational feedback is designed to deliver warm and positive message (e.g. good job!), and instructional feedback offers hints or cues to attain the correct responses. Preece, Rogers, and Sharp (2015) also stated that feedback provided to learners should be clear and instrumental.

Providing feedback based on learner's responses is enabled by the branching attribute in e-Learning software (Hazen, 1985; Weller, 1988).

Branching is a key component of interactivity that can be operationalized using multiple response or free response (Weller, 1998). Learner receives different treatments based on their responses, which can be described using the “if-else” statement. For instance, if the answer is A, go to step B or scenario B; if the answer is C, go to step D or scenario D; otherwise, continue to the next question. There are different types of branches, including liner, user-directed, and multiple-remediation (Schwier & Misanchuk, 1993).

- Screen and message design. According to Hazen (1985) and Weller (1988), well-designed screen and message can be a motivating factor for the learner to improve his or her response as well as continue the learning process. Pleasing look of an interface, including well-designed fonts and image, appropriate use of colors creates positive emotion (e.g. satisfaction and patience) in users. Well-organized text, image, and videos can enhance readability of the messages on the screen (Hazen, 1985; Preece et al., 2015).

Metaphor is used to help the learner obtain knowledge by associating unknown information with familiar concepts or objects (Chiou, 1992; Jones et al., 1995; Park & Hannafin, 1993; Wilson, 1995). Metaphor that the learner is familiar with can be used to design effective instruction and system interface, and those metaphors can either be visual or conceptual (Park & Hannafin, 1993). The book metaphor can be used to guide the design of a computer screen that looks like a book page, whereas the classroom metaphor indicates that learners can mentally map the learning activities in a physical classroom with those in a computer-based learning environment where learning is situated (Chiou, 1992).

However, Jones et al. (1995) also pointed out that not all learning programs needed to adopt a metaphor, and the content should be carefully examined to decide if a metaphor is needed.

With utilizing the powerful interactivity features of e-Learning authoring tools, essential components include learner control, navigation function, timely feedback and well-designed screen and messages are added to the interactive learning materials. Learner control allows the learner to plan learning goals and sequences, and timely feedback enables the learner to monitor the learning processes by receiving instant feedback. Plan and monitor are two critical metacognitive strategies, thus appropriate design of the interface and interactivity could facilitate metacognitive development. Well-designed interactive content could also provide individualized learning experience, foster learner engagement with the program and content, which improves learner motivation and enhances learning experiences (Kennedy, 2004; Weller, 1988).

Summary

Given the importance of metacognition on affecting learner performance, there is a need to design a metacognitive-based interactive content design framework with the following reasons. Firstly, with the massive distribution of computer-based learning materials that are produced using e-Learning authoring tools, rarely was the content used to teach or train metacognitive strategies. Secondly, even though instructional design principles have been used to guide the creation of e-Learning content, the addition of design principles of interface and messages could advance the research and design practice in interactive content design. Thirdly, despite the various interactivity attributes of e-Learning authoring tools with new features being added from time to time, the interactivity functions have not yet been fully explored regarding their effects on learning processes or outcomes. Fourthly, a significant number of the learning and training content produced using e-Learning authoring tools are purely practical, which lacks theoretical supports.

This study contributes to current research and practice in metacognition by developing an interactive content development framework to guide the design of interactive content using e-Learning authoring tools. The procedures to develop this framework are operationalized. Firstly, this study suggests effective metacognitive strategies from existing literature in relevant areas. Secondly, thorough investigation was conducted to explore the interactivity functions (e.g. media attributes) from a wide range of the e-Learning authoring tools. Thirdly, effective instructional strategies are proposed that utilize certain media attributes of e-Learning authoring tools to teach or train metacognition. These procedures result in a design framework to support the integration of metacognitive scaffolds into computer-based learning materials by leveraging the functional attributes of e-Learning authoring tools.

CHAPTER 3: RESEARCH METHODOLOGY

Research Purpose and Question

This study is conducted to design an interactive content development framework that aims to teach and train metacognitive strategies. The guidelines consolidate literature from metacognition, multimedia design, instructional design, interaction design and message design. Three key components were identified from the literature and included in this framework. Those components are metacognitive strategies, instructional strategies, and media attributes. The interactive content will be developed using e-Learning authoring tools with following the guidelines proposed in the framework. This guideline informs the practice in the field of instructional design and technology. Thus, the research question for this study is:

What features would a framework have to facilitate metacognitive strategy development in computer-mediated instruction?

Study Design

Design and Development Research

This study employs a design and development research (DDR) approach that is also called development research (Richey, Klein, & Nelson, 2004). DDR is defined as "the systematic study of the design, development and evaluation processes with the aim of establishing an empirical basis for the creation of instructional and non-instructional products and tools and new or enhanced models that govern their development" (Richey & Klein, 2007, p.1). Richey et al. (2004) and Richey and Klein (2014) described DDR as applied research and an inquiry technique that aims to create new knowledge and validate existing practice in the field of instructional design and technology. It embodies both design and research practices where these two components inform each other by linking theory to practice (Richey et al., 2004). The goal of research is to generate new knowledge, whereas the goal of design is to create products, tools, or models. Thus, the purpose of DDR is to create and deliver new knowledge via the design and development of products, tools, or models. There are two types of DDR, including type I - product and tool research and type Π - model research (Richey et al., 2004; Richey & Klein, 2005, 2007, 2014). Product and Tool development is context specific, in contrast, model research is more generalizable (Richey et al., 2004; Richey & Klein, 2007, 2014). Model research includes research on conceptual models and procedural models (Ross et al., 2007). Conceptual models focus on identifying key variables and the interrelationships among those variables, whereas procedural models suggest steps to include in the design process (Ross et al., 2007). To create a framework that guides the design of metacognitive interactive content, this study adopts type Π - model research method with focusing on suggesting key steps in designing metacognitive scaffolds in ill-structured problem solving contexts. Type II DDR emphasizes on the development, validation and use of models to guide the instructional design processes. The models can be developed by surveying designers and developers or synthesizing existing literature and design practices and validated by experts or through experiments (Richey & Klein, 2005). The product of type Π DDR can be a new, improved model or design principles (Richey & Klein, 2007). It is a unique developmental research method as the proposed model or design principles can be applied in various design and development contexts (Richey & Nelson, 1996; Richey & Klein, 2007).

This study consists of four major phases, which are analysis phase, design and development phases, evaluation phase, and revision phase. This study has two major areas of focuses that are model development and validation, which are key to DDR.

Study Procedure

Analysis. A systematic and thorough review and analysis of the existing literature on major components of metacognition and metacognitive strategies were performed. According to Richey and Klein (2005), literature review in type II studies covers the review of similar models, research on targeted process and factors impacting the process. Literature that is reviewed and analyzed in this study covers three areas, including metacognitive strategies, related instructional strategies, and interactive attributes of the e-Learning authoring tools as shown in Table 1. Literatures on those topics come from journal articles, dissertation, thesis, and e-Learning design practices published online. According to Richey and Nelson (1996), developmental studies aim to produce innovative design and development guidelines, design practices from real world environments can be included when research literature is not enough to propose a model or design principles. Key search terms include “metacognition”, “metacognitive skills”, “metacognitive strategies”, “interactivity”, “computer-based instruction”, “interaction design”, “message design”, and “screen design”.

Table 1

Design Elements of Interactive Content in Web-based Instruction

Questions	Sources
What are the metacognitive strategies?	Published Literature

What are the instructional strategies to teach metacognitive strategies/skills?	Published Literature
What media attributes could be used to create interactive instruction?	Web sources and investigation of interactivity attributes of multiple e-Learning authoring tools.

Design and development. The design and development phase is the construction of components and operationalization of the design procedures of interactive content design framework. This phase was carried out based on findings from the analysis phase where relevant literature on metacognitive strategies, instructional strategies and media attributes were identified and summarized.

Instructional strategies are learning activities or events planned and executed to help learners achieve performance goals (Seechaliao, 2017; Vázquez et al., 2018). Those strategies are designed based on learner characteristics, learning objectives, content and context (Seechaliao, 2017). Seechaliao (2017) implemented various instructional strategies, including brainstorming, collaboration, and providing feedback, to support creativity and innovation in education. Tepgeç and Çevik (2018) investigated the effects of instructional strategies that consist of restudying materials, testing and work example on retention performance. Based on the scope of this study, instructional strategies presented in this interactive content design framework are synthesized from existing empirical study, practical literature as well as designed by the researcher.

Evaluation. Once the metacognitive interactive content design guideline is completed during the design and development phase, it will be evaluated by experts in instructional design and metacognition research fields. Model validation methods include expert review, in-depth interview, field evaluation, and controlled testing (Richey & Klein, 2005, 2007). Expert review will be adopted as internal validation procedures (Ross et al., 2007) to evaluate the effectiveness of the developed framework in this study. This process occurs by asking experts to evaluate components, structure and application of the model (Ross et al., 2007).

To begin the evaluation process, the design framework along with the evaluation survey were emailed to the experts once they agreed to participate. Other evaluation methods, such as in-depth interview, filed evaluation and controlled testing could be used during the next phase of this study. The evaluation process consisted of two phases: pilot study and formal study. Preliminary feedback was collected from two scholar-practitioners in the pilot study to improve the framework and adjust expert review invitation messages and evaluation survey. Selected experts in instructional design, problem-solving, and metacognition were invited to participate in the formal phase of the evaluation.

Revision. During the revision phase, feedback from the experts was implemented to refine the framework. The feedback is presented in Chapter 5. The refined framework for guiding the development of metacognitive-based interactive content is included in the appendices.

CHAPTER 4: FRAMEWORK FOR DESIGNING METACOGNITIVE SCAFFOLDS IN ILL-STRUCTURED PROBLEM-SOLVING INSTRUCTION USING E-LEARING AUTHORING TOOLS

This chapter presents a descriptive framework for designing metacognitive scaffolds in ill-structured problem-solving instruction using eLearning authoring tools. It first introduces metacognitive scaffolds and problem space, and then describes ill-structured problem-solving stages, metacognitive strategies, instructional activities, and media attributes and examples. Tables that include those key attributes are added to the end of this chapter. This framework serves as instructional guidelines for instructional designers, instructors, and practitioners to design metacognitive scaffolds in various ill-structured problem-solving contexts.

Metacognition plays an important role in problem solving, especially in solving ill-structured problems, as it guides the learner to plan, monitor and evaluate their thinking process (Davidson, Deuser, & Sternberg, 1994; Ge & Land, 2003, 2004; Gordon, 1996; Jonassen, 2000; King, 1991; Lin, 1994; Lin et al.,1999). Researchers have implemented metacognitive scaffolds in instructional activities (Bulu & Pedersen, 2010; Ge & Land, 2003; Liu, Horton, Toprac, & Yuen, 2012) and found that metacognitive intervention could lead to improved learner performance (Ge & Land, 2003, 2004; Tzohar-Rozen & Kramarski, 2014). Commonly used metacognitive scaffolds in problem-solving instruction include prompting and modeling (Belland, Glazewski, & Richardson, 2008; Ge & Land, 2003; Hollingworth & McLoughlin, 2001; Lin et al., 1999). Question prompts helped learner externalize, monitor and understand their thinking processes (Lin et al., 1999; Lin & Lehman, 1999), which could enhance their metacognitive awareness

(Hollingworth & McLoughlin, 2001). Expert modeling was often presented in video demonstration, animation or simulation (Hollingworth & McLoughlin, 2001; Lin et al.,1999; Pedersen & Liu, 2002). According to the Zone of Proximal Development, novice learners expand their knowledge with the assistance from more advanced peers or teachers (Vygotsky, 1986). In a computer-based learning environment, interactive content could play the role of an expert or capable peer who assists less competent learners to achieve the learning goals that they won't be able to accomplish on their own. The "expert" in a hypermedia program can be a mediated character that assists the learner in problem-solving process (Pedersen & Liu, 2002).

Scholars believe that a continuum exists between ill-structured and well-structured problems, and there is no clear boundary between them (Simon, 1973; Voss, 1988). Ill-structured and well-structured problems share similar problem-solving procedures (Gick, 1986), such as problem representation, generate solutions, present a solution, evaluation and reflection. This framework presents detailed instruction that guides the design of metacognitive scaffolds to facilitate learners with solving ill-structured problems. Designers, instructors, and other stakeholders could use this framework to design problem-based interactive learning materials using e-Learning authoring tools, such as Adobe Captivate, Articulate Storyline, and Lectora. The interactive content allows the learner to control the pace of the learning and access the materials regardless of time and location and provides learner with instant feedback, which could increase learner motivation (Lin, 1994; Jones, 2009). This framework first introduces problem space, presents key problem-solving stages, and then describes relevant metacognitive strategies, instructional strategies, examples and interactive media types in each problem-solving stage. Those literature consists of research papers, book chapters, thesis and dissertations, as well as practical guidelines.

Key Components of the Framework

Problem Space

Constructing a problem space is essential for solving an ill-structured problem (Jonassen, 2000). Problem space refers to the space or internal environment that contains all variables, goals, constraints, paths and stages in transforming the current state of a problem to its ideal state (Newell & Simon, 1972; Voss, 1988). There are no algorithms or rules to follow to solve ill-structured problems as those that would be used for solving well-structured problems (Jonassen, 1997, 2000). Learners need to consider various paths, stages and solutions in a problem space (Jonassen, 1997, 2000). This may seem challenging for novice learners, therefore, Jonassen (2000) urged designers to construct problem space for learners, especially for beginners. By implementing appropriate metacognitive scaffolds (e.g. question prompts) in learning content, computer-based instruction could help learners construct problem space and guide them through the ill-structured problem-solving process.

Ill-structured Problem-solving Stages

Ill-structured problem-solving instruction can be created with following general ill-structured problem-solving procedures as shown in Table 2. Those stages contain problem representation (Belland et al., 2008; Ge & Land, 2003; Kale et al., 2018; Sinnott, 1989; Swanson, 1990), generate solutions (Belland et al., 2008; Chi, Glaser, & Rees, 1982; Ge & Land, 2004; Sinnott, 1989), present a solution (Belland et al., 2008; Ge & Land, 2003, 2004), evaluation (Davidson et al., 1994; Ge & Land, 2003, 2004; Lin, Newby, Glenn, & Foster, 1994; Jonassen, 1997), and reflection (Kauffman, Ge, Xie, & Chen, 2008; Kim & Hannafin, 2011) as seen in Figure 1. Different from well-structured problem solving, ill-structured problem-solving procedures are not linear, and they are situated (Jonassen, 1997, 2000; Voss, 1988), dynamically intertwined, circular, and iterative (Ge, Law, & Huang, 2016). Metacognition guides the problem-solving process by monitoring and controlling the learner's thinking process (as presented in Figure 1). This may cause changes in problem representation and solution path. For example, the entire process of playing chess is defined as solving an ill-structured problem (Simon, 1973), however, the player needs to redefine the problem space and regenerate solutions after each move he or she makes.

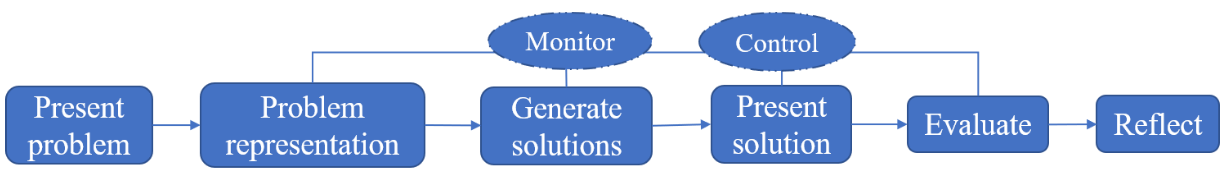

Figure 1. Metacognition-based Ill-structured Problem-solving Process

The initial stage of creating metacognitive-based ill-structured problem-solving instruction is to present the problem. Problems presented in the learning materials should be situated and based on real-world scenarios, which could foster transfer of knowledge (Lin et al., 1994; Liu et al., 2012; Park & Hannafin, 1993). This means that learner could apply the acquired knowledge and skills in other contexts by taking anchored instruction (Liu et al., 2012). As more scholars regarded solving ill-structured problems as a design process (Ge & Land, 2003, 2004; Jonassen, 1997, 2000), examples of ill-structured problems may include designing a house or proposing a plan to reduce air pollution.

Problem representation. A problem appears ill-structured if the problem statement is vague with no specified goals or constraints (Chi et al., 1982; Jonassen, 1997; Shin et al., 2003; Voss, 1988). The problems and goals are not measurable or predictable, and approaches to reach the goals also vary from case to case. The purpose of problem representation is to understand and form the initial state of the problem (Voss, 1988), such as identifying cause(s) of the problem and setting goals. This process is complex, which also requires the learner to discover missing information, differentiate relevant information from irrelevant information, and express personal opinions of the problem (Jonassen, 1997, 2000). To assist learner with developing a problem representation, metacognitive scaffolds could be created to facilitate learner with identifying all causes, constraints of a problem (Ge & Land, 2003; Jonassen, 1997; Voss, 1988), as well as various solution paths (Jonassen, 1997).

Instead of using general rules or principles, schemata are vital for interpreting new problems in ill-structured problem scenarios (Chi et al., 1982; Ge & Land, 2004). Schemata are mental structures that represent relationships and connections between objects, events and contexts in long-term memory (Chi et al., 1982; Gick, 1986). Each scheme contains information (e.g. goals, constraints, and procedures) related to a certain problem type (Gick, 1986; Jonassen, 2000), and they are formed based on one’s past experiences (Gick, 1986; Jonassen, 1997, 2000). If a problem seems familiar, pertinent scheme will be activated (Chi et al., 1982; Gick, 1986), learner can skip the solution generation stage and proceed to present solution stage directly. Otherwise, a general problem-solving procedure will be activated to guide the learner to search for appropriate strategies to solve the problem (Chi et al., 1982).

Generate solutions. Once the initial state of an ill-structured problem is constructed, learner moves on to generate solutions. According to Shin et al. (2003), ill-structured problem could possess more than one solution with multiple solution paths. Jonassen (1997) viewed that multiple solutions resulted from different problem representations. He also stated that a solution was chosen based on the solver's view of the causes and constraints of a problem. Sinnott (1989) named this process as creative exercises, which cultivates divergent thinking.

In this stage, learner needs to develop possible solutions with supporting evidence (Belland et al., 2008), which requires and fosters argumentation skills. Belland et al. (2008) asserted that argumentation is key to solving ill-structured problems. For each argument the learner makes, evidence is needed to support the claims. This process requires information identification, strategy selection, data collection and action plan formulation. In addition to considering various solutions and solution paths, criteria for evaluating the solutions also need to be proposed (Shin et al., 2003; Swanson, 1990).

Solution presentation and evaluation. Once a solution is chosen, it will be verified and evaluated (Garofalo & Lester, 1985; Kwang, 2000). Huttenlock (2007) suggested to evaluate both the process and goal completion in an ill-structured problem domain. The evaluation of goal completion focuses on checking if they have enough information to confirm their claims or reach the preset goals, whereas, process evaluation emphasizes on choosing appropriate data and strategy during the process (Huttenlock, 2007). Jonassen (1997) proposed to evaluate the viability of solutions by asking questions, such as "Was the problem solved? Did it adhere to the constraints?". As ill-structured problems have divergent solutions, it is critical for learners to justify their decisions by explaining why the chosen solution would work (Belland et al., 2008; Bulu & Pedersen, 2010; Lin & Lehman, 1999; Shin et al., 2003).

In addition to justifying the solution, scholars also recommended to evaluate the supporting evidence and information (Bulu & Pedersen, 2010), check with evaluation criteria (Jonassen, 1997; Swanson, 1990), and identify side effects (Ge & Land, 2004; Simon, 1973) in this stage.

Reflection. Reflection is the last stage in ill-structured problem-solving process. During this stage, learner revisits ideas, process, adopted strategies, and solutions (Collins & Brown, 1988; Kim & Hannafin, 2011). Learning occurs when learner reflects on their own mistakes and plans for improvement and knowledge transfer in other contexts. Collins and Brown (1988) also stated that computer could be used as an effective medium to facilitate the reflection process by recording and presenting thinking process.

Table 2

Ill-structured Problem-solving Stages

Stages	Literature
Problem representation	Decide about the essence or nature of the problem (Sinnott, 1989); Define, generate and pursue learning issues to understand the problem (Belland et al., 2008); Understand a situation, information, main features/mechanism (Kale et al., 2018); Presentation, understanding, or definition of problem (Swanson, 1990); Problem representation (Ge & Land, 2003).
Generate solutions	Develop a possible solution ((Belland et al., 2008); Search for a solution (Chi et al., 1982); Choose and generate solutions (Sinnott, 1989); Solution development (Ge & Land, 2004).
Present a solution	Present their solution and the evidence to support it (Belland et al., 2008); Provide justifications (Ge & Land, 2003, 2004).

Evaluation	Monitor and evaluation (Ge & Land, 2003, 2004); Solution evaluation (Davidson et al., 1994); Evaluate (Lin et al., 1994); Assess problem solution (Jonassen, 1997).
Reflection	Reflection and negotiation (Kim & Hannafin, 2011); Reflect on work (Kauffman et al., 2008).

Metacognitive Strategies and Instructional Activities

Metacognitive strategies are vital for solving ill-structured problems by monitoring and controlling cognitive processes (Brown et al., 1994; Efklides, 2008; Flavell, 1987). They are used throughout the problem-solving process by planning tasks, selecting cognitive strategies, and making revision (Akturk & Sahin, 2011; Paris & Winograd, 1990). According to Shin et al. (2003), metacognitive skills, such as planning, and monitoring are strong predictors of the success in solving unfamiliar ill-structured problems. Five metacognitive strategies are presented in this framework, which are Orienting (Bannert & Reimann, 2012; Garofalo & Lester, 1985; Meijer, Veenman, & van Hout-Wolters, 2006; Molenaar & Chiu, 2014), Planning (Brown, 1987; Gordon, 1996; King, 1991; Kirsh, 2005; Molenaar & Chiu, 2014; Pintrich, 2002; Shin et al., 2003; Zimmerman, 2006), Monitoring (Brown, 1987; Efklides, 2014; Gordon, 1996; King, 1991; Kirsh, 2005; Pintrich, 2000; Zimmerman, 2006), Evaluation (Bannert & Reimann, 2012; Brown, 1987; Gordon, 1996; Meijer et al., 2006; Molenaar & Chiu, 2014; Schmidt & Ford, 2003; Yıldız-Feyzioğlu, Akpınar, & Tatar, 2013), and Reflection (Meijer et al., 2006; Molenaar & Chiu, 2014; Moreno & Mayer, 2007; Pintrich, 2000; Zimmerman, 2006).

Instructional scaffolds could be used to support those metacognitive strategies in solving ill-structured problems (Ge & Land, 2003, 2004). This section introduces metacognitive strategies and relevant instructional scaffolds that could be created using eLearning authoring tools. Scaffolds consist of two categories: question prompts and expert modeling. In addition to regulating learners' thinking processes, this framework also introduces scaffolds that help learners raise metacognitive awareness (e.g. ease of learning) and help them cope with negative emotions. Pekrun, Goetz, Titz and Perry (2002) stated that difficulty encountered in resolving academic problems may cause anxiety that hinders motivation, whereas appropriate emotion scaffolding could enhance learner motivation (Kim & Pekrun, 2014). Emotion regulation scaffolds can be created using question prompts, such as "Is this problem easy or hard?", which is shown in Table 3. If learner indicates that this problem is very hard, expert modeling will be provided to assist learner with solving the problem and sustain learner motivation.

Orienting. Garofalo and Lester (1985) defined orienting as a strategic behavior to understand and assess a problem. Meijer et al. (2006) asserted that experts spent more time than beginners on orientation activities. Orienting occurs during problem representation stage, and orienting activities include understand the problem (Belland et al., 2008; Kale et al., 2018), examine causes of the problem (Jonassen, 1997; Kauffman et al., 2008; Voss, 1988), identify relevant and irrelevant information (Hollingworth & McLoughlin, 2001; Swanson, 1990) as well as constraints, variables, and relations (Ge & Land, 2004; Kale et al., 2018; Voss, 1988).

Orienting skills could be trained using question prompts in computer-based instruction, such as "What are the causes of the problem?" (Kauffman et al., 2008), "What information is relevant to solve this problem and what information is irrelevant?" (King, 1991), and "What are the key variables of this problem and how are they related?"

(Meijer et al., 2006). More examples can be seen in Table 3.

Planning. Tzohar-Rozen and Kramarski (2014) defined planning as a skill of choosing strategies and allocating resources. It is applied in problem representation and generating solutions stages. In problem representation stage, planning activities include activating prior knowledge and experience (Huttenlock, 2007; Meijer et al., 2006; Shahbodin & bt Bakar, 2010; Yıldız-Feyzioğlu et al., 2013), setting goals (Bannert & Reimann, 2012; Garofalo & Lester, 1985; Yıldız-Feyzioğlu et al., 2013), and formulating hypothesis (Bogard, Liu, & Chiang, 2013; Gick, 1986; Meijer et al., 2006; Swanson, 1990). During the solution generation phase, planning activities contain formulating action plan (Huttenlock, 2007; Kapa, 2001; Meijer et al., 2006), identifying needed information (Bulu & Pedersen, 2010; Huttenlock, 2007; Swanson, 1990), and selecting strategy (Huttenlock, 2007). Learning resources could be integrated into the e-Learning content to assist learner with locating information and setting goals.

Planning scaffolds can be designed as question prompts, such as “Do you have any related experience with this kind of problem?” (Shahbodin & bt Bakar, 2010), “What are possible solutions of this problem?” (Ge & Land, 2003; Shahbodin & bt Bakar, 2010), “What are the steps to solve this problem?” (Hollingworth & McLoughlin, 2001; Shahbodin & bt Bakar, 2010). When a True/False or Multiple Choice question is used to design a question prompt, pertinent system feedback will be provided based on learner’s response, such as providing cues or hints when learner answers the question incorrectly. More information on planning scaffolds and examples can be found in Table 3 and Table 4.

Monitoring. Monitoring refers to one’s awareness of task comprehension and performance (Schraw, 1998; Tzohar-Rozen & Kramarski, 2014). Quintana, Zhang and Krajcik (2005) described monitoring activities as identifying tasks, evaluating work progress and predicting outcomes. Monitoring occurs throughout the problem-solving process, which includes the monitoring of cognitive process and learner emotion. Monitoring emotion concerns the monitoring of feelings and judgement, which relates to the awareness of metacognitive experiences (Efklides, 2014). It is through the monitoring of metacognitive experience that the learner adjusts their actions in the problem-solving process, such as initiate or terminate tasks (Efklides, 2014).

Examples of monitoring prompts include “Is this problem easy or hard?” (Tzohar-Rozen & Kramarski, 2014), “Are you reaching your goals?” (Huttenlock, 2007), and “Are you using the strategy that you chose?” (Kwang, 2000). Appropriate system feedback will be provided based on learner’s response to each question. In addition, expert modeling will be offered when learner expresses difficulties in completing tasks. Expert modeling can be provided via video demonstration or in simulation environment. More monitoring scaffolds and examples can be found in Table 4.

Evaluation. Evaluation strategies are used in the evaluation stage of solving ill-structured problems, which serves the purpose of justifying proposed solution and process (Tzohar-Rozen & Kramarski, 2014). Metacognitive scaffolds adopted in this phase are specified as the assessment of supporting information (Bulu & Pedersen, 2010) and defending of a chosen solution (Ge & Land, 2004). However, if the chosen strategy does not meet the evaluation criteria, learner needs to restart the problem-solving process. It is through evaluation that the learner refines their working process and outcomes. Question prompts that are used to foster metacognitive evaluation can be presented as

"What are your reasons and/or arguments for proposing this solution?" (Ge & Land, 2003) and "Have you taken into account the perspectives of different stakeholders?" (Ge & Land, 2004). More related strategies and examples are described in Table 5.

Reflection. Designing metacognitive scaffolds to facilitate learner reflection is the last stage in creating computer-based ill-structured problem-solving instruction. Reflection is a metacognitive strategy (Meijer et al., 2006; Molenaar & Chiu, 2014; Moreno & Mayer, 2007; Pintrich, 2000; Zimmerman, 2006) used to solve problems (Lin et al., 1999). It helps the learner develop an understanding of oneself and related events in order to inform future actions (Sandars, 2009). Guided reflection and feedback could challenge learners meanwhile help them develop a deeper understanding of related content area (Sandars, 2009). The rich interactive features of multimedia-enhanced problem-solving instruction provides new means to support those reflective activities (Gordon, 1996; Liu et al., 2012). Relevant scaffolds are presented in Table 6, such as "What did you learn from this problem?", "Can you think of other setting where those skills could be applied?", and "What are the pros and cons of the chosen solution?" (Bulu & Pedersen, 2010; Ge & Land, 2004).

Media Attributes and Examples

Interactive features in e-Learning authoring tools can be used effectively to design metacognitive scaffolds. The rich affordability of e-Learning authoring tools allows designers, instructors, and other stakeholders to present a problem with utilizing a wide variety of media attributes, such as text, audio, video, simulation and animation. Text can be added by adding a textbox; audio can be made using audio recording or text-to-speech; Videos can be created by uploading a pre-recorded video or linking to a YouTube video;

Highly interactive animation and games could also be created using the advanced features in e-Learning authoring tools.

Interactive media types presented in this framework were identified from a variety of e-Learning authoring tools, and examples were created using Adobe Captivate (see Figure 2 as an example). Those media types can be selected from the menu bar of eLearning authoring tools, which includes Text Box, Short Answer, True/False, Multiple Choice, Checkbox, Radio Button, Hyperlinks, Audio Input, and Animation ("Articulate Storyline," 2012; "Captivate User Guide," n.d.). This framework aims to provide guidelines for instructors and designers to create metacognitive scaffolds in problem-based instruction. Instructional designers and instructors can choose from those suggested features to design appropriate metacognitive scaffolds. For instance, to create a question prompt, either a Multiple Choice question or Short Answer can be used. However, instructors and designers can be creative in designing the instruction with altering the suggested instructional activities included in this framework or create new learning events using their preferred media features in e-Learning authoring tools.

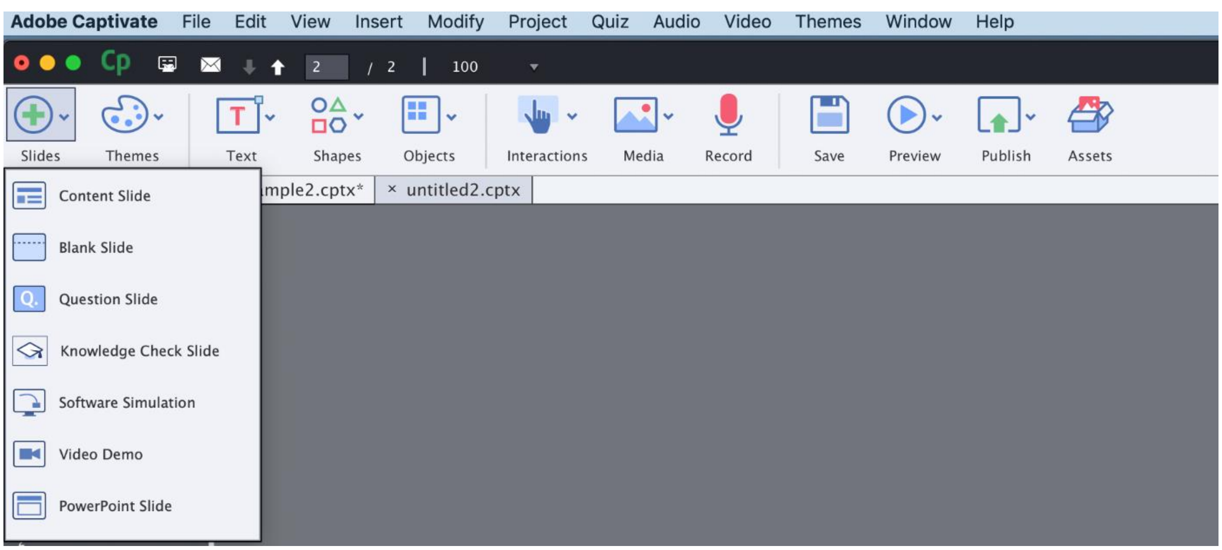

Figure 2. Adding Slides in Captivate

Ill-structured problem-solving instruction can vary from simple courseware to animation and educational games with utilizing more advanced functions in e-Learning authoring tools. Because ill-structured problems may have multiple solutions (Ge & Land, 2003, 2004; Jonassen, 1997, 2000), and scaffolds included in this framework could foster divergent thinking (Jonassen, 1997) by prompting learners to consider all aspects of the problem and all possible solutions. When the learner has difficulty in finding enough information for solving a problem, the interactive instruction will direct him or her to relevant resources. If the learner does not make adequate progress, it will provide learner with cues and hints to proceed in the problem-solving process.

Instruction produced using this framework offers personalized learning experiences by directing learners to different learning paths based on their interactions with the learning materials. This could be done using Branching function. Branching is a key feature that makes personalized learning experience possible (Domazet & Gavrilović, 2015; Piecha, 2004; Weller, 1988), and it provides learner with pertinent feedback via answer validation (Piecha, 2004). Good feedback practices deliver high quality information, facilitate learners reflect on their learning processes, and improve learner performance, which in turn help learners develop self-regulation skills (Nicol & Macfarlane-Dick, 2006). Feedback can be presented with directing learner to the next question, an expert demonstration, or the end of the learning module. Many interactive media types, such as Multiple Choice, True/False, and Drag and Drop, contain the feedback function. Clarifying or exploratory questions, such as "can you explain…" could be asked to help learners monitor and evaluate their learning (Molloy & Boud, 2014). The following paragraphs elaborate on different interactive media types and examples for creating metacognitive scaffolds using those interactive media types.

Multiple Choice. Multiple Choice is a commonly used feature in eLearning authoring tools. It provides learner with pertinent feedback based on the selected answer(s). Figure 3 shows an example of monitoring scaffolds with using branching function to direct the learner to different learning paths, such as "Go to the previous slide", "Go to the next slide", or "Open URL or file". Like Multiple Choice, True/False, Checkbox and Radio Button can be used to fulfill the same purpose with assigning variables in Advanced Action in Adobe Captivate ("Create learning interactions," n.d.) and adding triggers and converting to freeform interaction in Storyline 360 (Fair, n.d.).

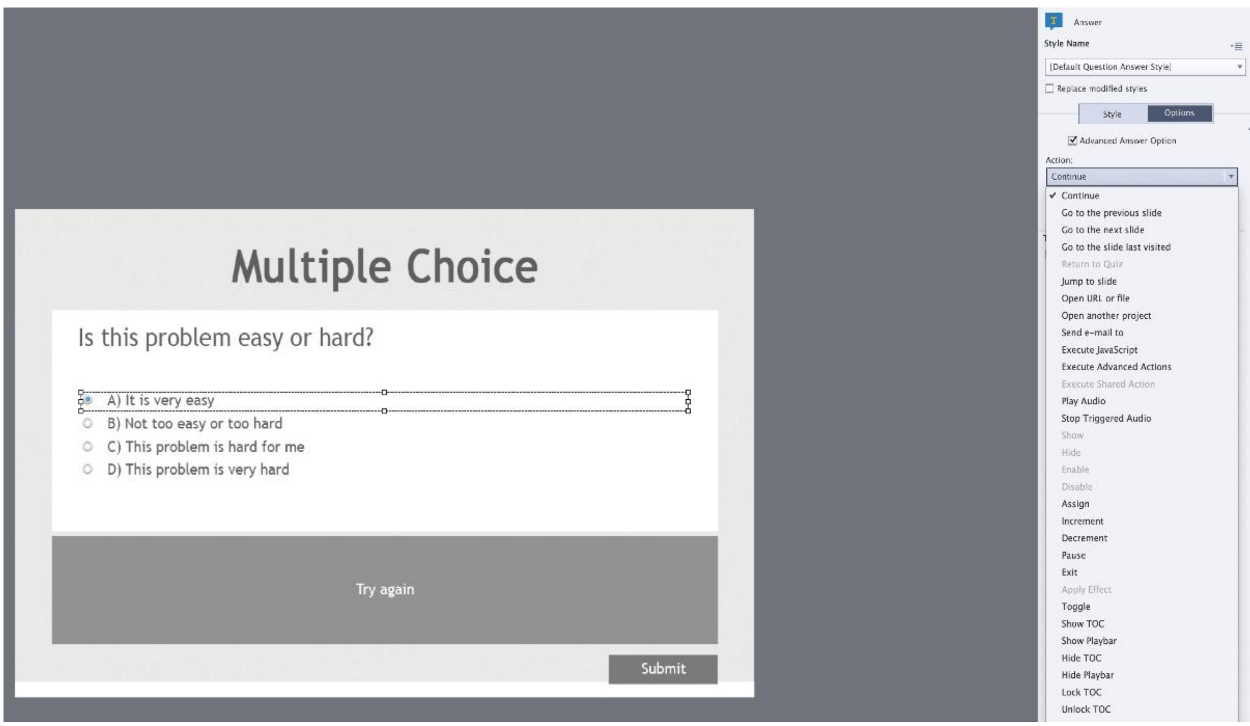

Figure 3. Adding Advanced Actions in Captivate

Short Answer. Short Answer is regarded as an open-ended question, which prompts learner to respond to a question briefly with putting their thoughts into words (Pappas, 2015a). A planning scaffold created using Short Answer Question and Button (e.g. Clear and Submit) in Captivate is shown in Figure 4, which asks the learner to present needed information and knowledge to solve a problem. Short Answer is also an ideal question format to train learner's argumentation and justification skills by asking learner to describe different solution paths and explain why they choose a solution.

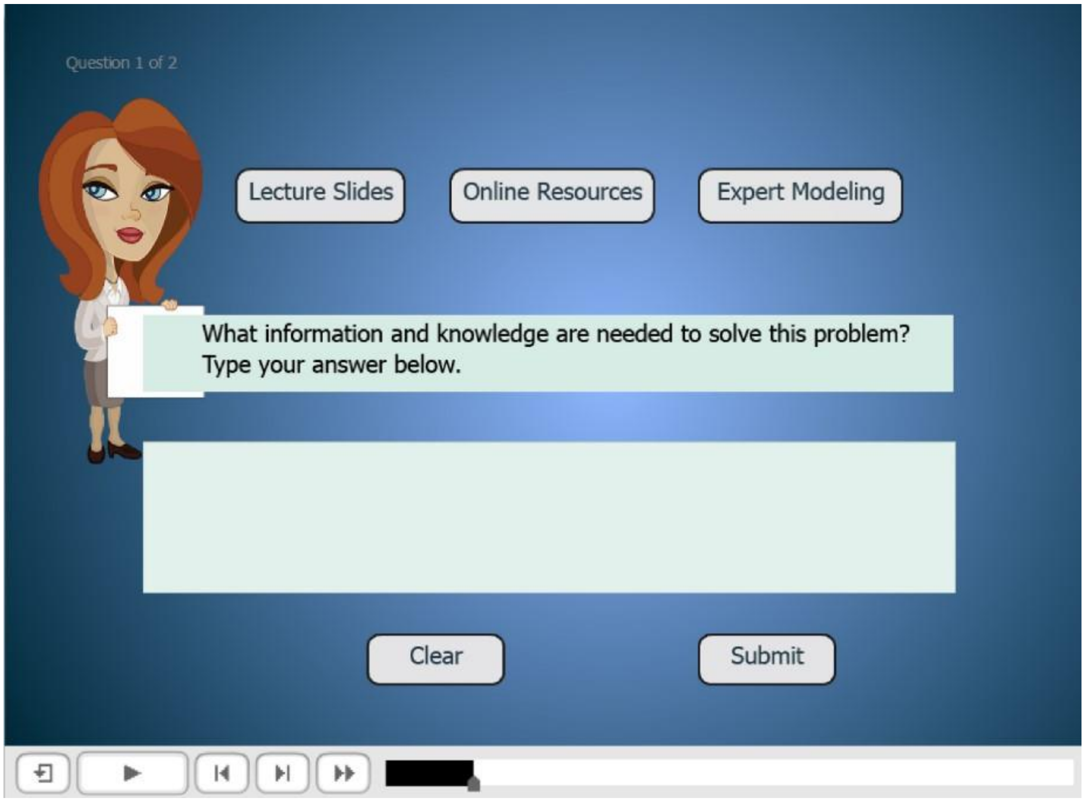

Figure 4. Sample Image of Metacognitive Scaffolds in Justifying Solution Stage

Text-to-speech. Text-to-speech allows the instructor and course designer to create audio from written texts or scripts (Fair, n.d.). Text-to-speech can be used to present a problem or elaborate on a topic in audio format in any stage of ill-structured problem-solving process. It helps e-Learning developers who are not native English speakers to produce audio narration. In addition, Text-to-speech is a great tool to design computer-based interactive content for visually impaired learners as well as learners who prefer audio instruction over plain texts.

Drag-and-drop. Drag and drop function is widely acknowledged for creating engaging and immersive e-Learning experiences (Pappas, 2015b). It allows the learner to drag a target and drop it to a correct spot, which could be used to match, sort and label items. This feature can be used to create educational games where learner tries as many times as possible until they complete the task successfully. Figure 5 shows an orienting scaffold created using Drag and Drop feature in Captivate to differentiate causes and non-causes of air pollution.

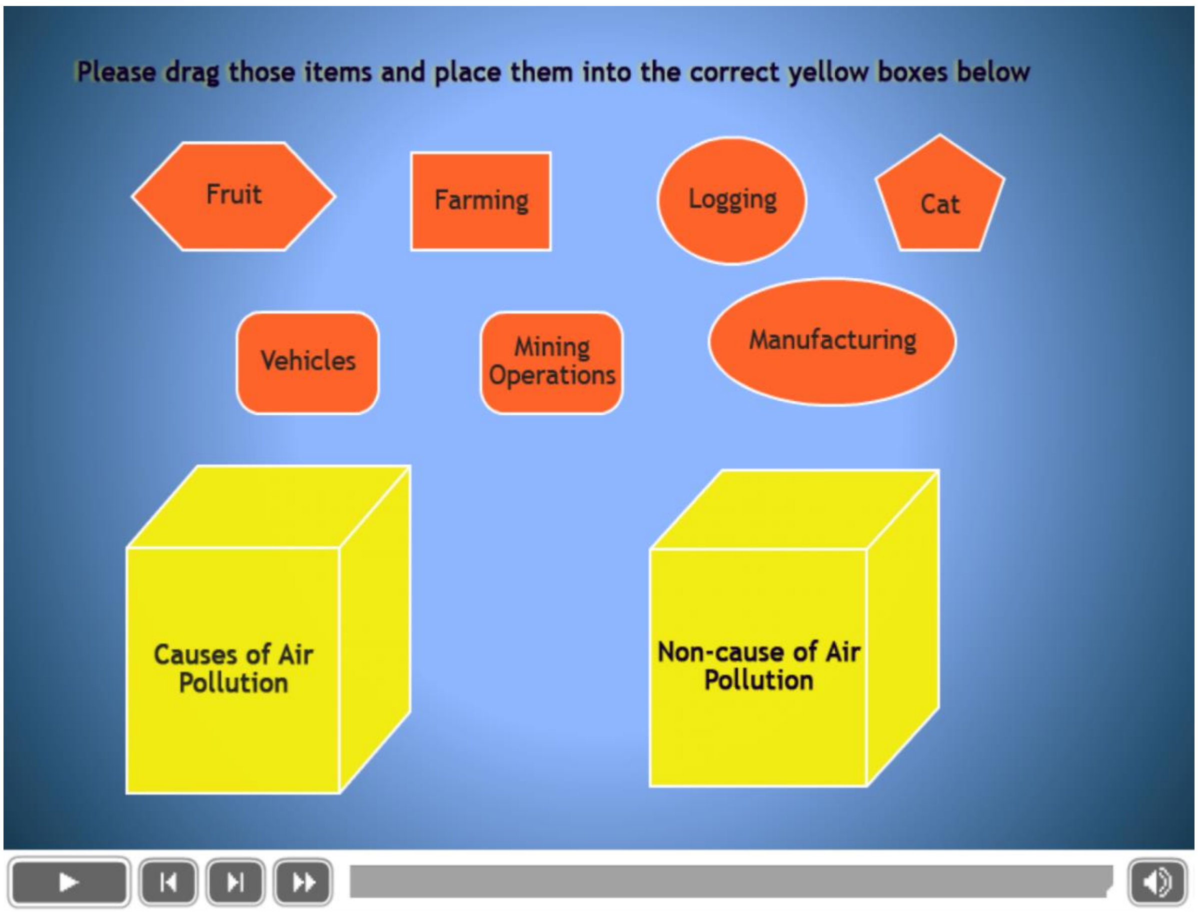

Figure 5. Problem Orienting Activity Designed Using Drag and Drop

Notes. Notes widget is used to create e-Learning materials that allow learners to take notes during learning process ("Use the Learner Notes," 2018). Note-taking is an important learning strategy (Ackerman & Lauterman, 2012) that enhances knowledge retention (Özsoy, Memiş, & Temur, 2017). It is a process where learner organizes and comprehends information to create mental representation of new knowledge (Trevors, Duffy, & Azevedo, 2014). Trevors et al. (2014) found that metacognitive scaffolds could reduce shallow note-taking behaviors (e.g. reproducing learning content) of learners with low prior knowledge. This implies that implementing metacognitive scaffolds with note-taking features in e-Learning content could potentially help learners with developing higher-level thinking skills while reducing rote learning behaviors.

In addition to Multiple Choice, Short Answer, Text-to-Speech, Drag and Drop, and Notes, other media types, such as Hyperlinks and Highlight Box (Jonassen, 2000), Matching (Pappas, 2015c), Hotspot (Brooks, n.d.) are also available across various e-Learning authoring tools. Those features can be used to create more complex ill-structured problem-solving learning materials and environments, such as Educational Games (Pappas, 2015b), Simulation (Mahboubian, 2009), Virtual Reality (Katsionis & Virvou, 2008), and Augmented Reality (Liarokapis, Petridis, Lister, & White, 2002; Jee, Lim, Youn, & Lee, 2014).

Table 3

Design of Computer-based Metacognitive Scaffolds in Problem Representation Stage

Metacognitive strategies	**Instructional strategies**	**Example**	**Interactive media type**	**System feedback**
Orienting (Bannert & Reimann, 2012; Garofalo & Lester Jr,1985; Meijer, Veenman, & van Hout-Wolters, 2006; Molenaar & Chiu, 2014)	Understand problem (Belland, Glazewski, & Richardson, 2008; Kale et al., 2018)	Do you understand the problem?	True/False Checkbox Radio Button Audio Input Notes Highlight Box Hyperlink	IF learner answers "Yes", he/she will be prompted to explain the problem using his/her own words (Kim & Hannafin, 2011; King, 1991; Kramarski & Friedman, 2014). IF learner answers "No", he/she will be suggested to reread the question and pay attention to highlighted words and hypertexts in problem statement.
	Examine causes of the problem (Jonassen, 1997; Kauffman, Ge, Xie, & Chen, 2008; Voss, 1988)	What are the causes of the problem? (Kauffman et al., 2008) Or The causes of the problem are___	Audio Input Short Answer Text Entry Box Notes Fill-in-The-Blank	
	Identify relevant and irrelevant information (Hollingworth & McLoughlin, 2001; Swanson, 1990)	What information is relevant to solve this problem and what information is irrelevant? (King, 1991)	Drag and Drop Multiple Choice Short Answer Text Entry Box Radio Button Audio Input Notes	Learner will receive error message if he/she answers the question incorrectly

Planning (Brown, 1987; Gordon, 1996; King, 1991; Kirsh, 2005; Molenaar & Chiu, 2014; Pintrich, 2002; Shin, Jonassen, & McGee, 2003; Zimmerman, 2003)	Identify constraints, parts, variables, relations (Ge & Land, 2004; Kale et al., 2018; Voss, 1988)	What are the key variables of this problem and how are they related? (Meijer et al., 2006)	Short Answer Text Entry Box Drag and Drop Radio Button Audio Input Notes	
	Identify missing information (Ge & Land, 2004)	What information is missing? (Ge & Land, 2004) Or Missing information includes___	Short Answer Text Entry Box Notes Checkbox Radio Button Audio Input Fill-in-The-Blank	
	Identify available resources/information (Bannert & Reimann, 2012)	What resources or information are available to solve the problem? Or Available resources/information to solve this problem include___	Short Answer Text Entry Box Notes Checkbox Radio Button Audio Input Fill-in-The-Blank	
	Activation of prior knowledge and experience (Huttenlock, 2007; Meijer et al., 2006; Shahbodin & Bakar, 2010; Yıldız-Feyzioğlu, Akpınar, & Tatar, 2013)	Do you have any related experience with this kind of problem? (Shahbodin & Bakar, 2010)	True/False Text Entry Box Audio Input Notes Button Hyperlinks Interactive video Animation Simulation	IF learner answers “Yes”, he/she will be prompted to elaborate on his/her relevant experience to this problem. IF learner answers “No”, he/she will be suggested to study the lecture slides and online resources provided in this module.
	Goal Setting (Bannert & Reimann, 2012; Garofalo & Lester,	What is/are your goal(s) and/or sub-goals for solving this problem?	Short Answer Text Entry Box Audio Input	

	1985; Yıldız-Feyzioğlu et al., 2013)	Or My goal(s) and/or sub-goals for solving this problem is/are ____	Notes Fill-in-The-Blank
	List needed knowledge/information (Shahbodin & Bakar, 2010)	What information and knowledge are needed to solve this problem? Or To solve this problem, ____ are needed	Short Answer Text Entry Box Audio Input Notes Drag and Drop Checkbox Radio Button Fill-in-The Blank

Table 4

Design of Computer-based Metacognitive Scaffolds in Generating Solutions Stage

Metacognitive strategies	Instructional strategies	Example	Interactive media type	System feedback
Planning (Brown, 1987; Gordon, 1996; King, 1991; Kirsh, 2005; Molenaar & Chiu, 2014; Pintrich, 2002; Shin, Jonassen, & McGee, 2003; Zimmerman, 2003)	Propose solutions (Shahbodin & Bakar, 2010)	What are possible solutions for this problem? (Ge & Land, 2003; Shahbodin & Bakar, 2010) Or Solutions of this problem include ___	Short Answer Text Entry Box Audio Input Notes Fill-in-The-Blank	
	Formulate action plan (Huttenlock, 2007; Kapa, 2001; Meijer et al., 2006)	What are the steps to solve this problem? (Hollingworth & McLoughlin, 2001; Shahbodin & Bakar, 2010) Or Steps to solve this problem include___	Short Answer Audio Input Text Entry Box Notes Fill-in-The-Blank	
	Select strategy (Huttenlock, 2007)	Which strategy/strategies will you use? (Tzohar-Rozen & Kramarski, 2014) Or Strategy/Strategies that you will use to solve this problem include___	Short Answer Audio Input Text Entry Box Notes Fill-in-The-Blank	
	Identify needed information (Bulu & Pedersen, 2010;	What information do you need to solve this	Short Answer Audio Input	

	Huttenlock, 2007; Swanson, 1990)	problem? (Bulu & Pedersen, 2010) Or To solve this problem, you will need_____ (Bulu & Pedersen, 2010)	Text Entry Box Checkbox Radio Button Notes Fill-in-The-Blank	
	Find information/data (Bannert & Reimann, 2012)	Where can you find the information? (Bannert & Reimann, 2012) Or You can find information from ___	Short Answer Text Entry Box Audio Input Notes Fill-in-The-Blank	
	Propose evaluation criteria (Swanson, 1990)	What are the necessary elements of an acceptable problem solution? (Belland, 2013) Or Components that need to be included in the problem solution are___	Short Answer Text Entry Box Audio Input Notes Fill-in-The-Blank	
Monitor (Brown, 1987; Efklides, 2014; Gordon, 1996; King, 1991; Kirsh, 2005; Pintrich, 2000; Zimmerman, 2003)	Data/Information generation (Huttenlock, 2007)	Do you find the information you need to solve the problem?	True/False Checkbox Radio Button Audio Input	IF learner answers "Yes", he/she will be prompted to answer the next question. IF learner answers "No", message says "you can find relevant information by clicking into the resources tab at the top" will appear on the screen.
	Goal checking (Bannert & Reimann, 2012)	Are you reaching your goals? (Huttenlock, 2007)	True/False Checkbox Radio Button Audio Input	IF learner answers "Yes", message says "good job!" will appear on the screen.

				IF learner answers “No”, message says “Keep working. You will get there!” will appear on the screen.
	Strategy implementation (Kwang, 2000)	Are you using the strategy that you chose? (Kwang, 2000)	True/False Checkbox Radio Button Audio Input Short Answer Text Entry Box	IF learner answers “Yes”, he/she will be prompted to the next question. IF learner answers “No”, message says “Could you please explain why you are not using a chosen strategy, and what new strategy/strategies are you using?” will be displayed.
	Check progress (Bulu & Pedersen, 2010; Ge & Land, 2003, 2004; King, 1991; Kwang, 2000)	Are you on the right track?	Multiple-Choice Checkbox Radio Button Audio Input Backward Button	IF learner answers “Yes”, message says “Keep the good work!” will appear on the screen. IF learner answers “No, I am lost”, message says “Please review your plans, which may help you get back on track” will appear on the screen. IF learner answers “No, I am stuck”, message says “You may start with solving parts of the problem or work backwards first” will appear on the screen.

Table 5

Design of Computer-based Metacognitive Scaffolds in Solution Presentation and Evaluation Stages

Metacognitive strategies	**Instructional strategies**	**Example**	**Interactive media type**	**System feedback**
	Justify proposed solution (Bulu & Pedersen, 2010; Ge & Land, 2003,2004; Kauffman et al., 2008; Meijer et al., 2006)	What are your reasons and/or arguments for proposing this solution? (Ge & Land, 2003) Or Your selected this solution because of___ (Bulu & Pedersen, 2010)	Short Answer Text Entry Box Notes Fill-in-The-Blank	
Evaluation (Bannert & Reimann, 2012; Brown, 1987; Gordon, 1996; Meijer et al., 2006; Molenaar & Chiu, 2014; Schmidt & Ford, 2003; Yıldız-Feyzioğlu et al., 2013)	Assessment of supporting evidence/information (Bulu & Pedersen, 2010)	Is your evidence appropriate to convince someone of your solution?	Multiple Choice Checkbox Radio Button Backward Button Notes	IF learner answers "Yes", he/she will be prompted to explain why the evidence supports the proposed solution. IF learner answers "Not sure" or "Don't know", he/she will be suggested to return to the last section to re-plan, re-collect and re-evaluate the evidence and solution.
	Check with evaluation criteria (Swanson, 1990)	Did your solution meet the pre-set evaluation criteria?	Multiple Choice Checkbox Radio Button Audio Input Backward Button	IF learner answers "Yes", message says "Good job!" will appear on the screen. IF learner answers "Not sure" or "Don't know", message says "Please review your evaluation criteria and refine your solution accordingly" will appear on the screen.
	Consider perspectives from all stakeholders (Ge & Land, 2004)	Have you taken into account the perspectives of different stakeholders?	Multiple Choice Checkbox Radio Button	IF learner answers "Yes", message says "Great!" will appear on the screen.

		(Ge & Land, 2004)	Audio Input Backward Button	IF learner answers “Not sure” or “No”, he/she will be prompted to the previous section to rework on the problem.
	Identify side effects (Ge & Land, 2004)	Did you point out the side effects and way(s) to reduce them when presenting your solution?	Multiple Choice Checkbox Radio Button Audio Input Backward Button	IF learner answers “Yes”, message says “Fantastic!” IF learner answers “No” or “Not sure”, system will suggest the learner to refine the solution with analyzing side effects.

Table 6

Design of Computer-based Metacognitive Scaffolds in Reflection Stage

Metacognitive strategies	Instructional strategies	Example	Interactive media type	System Feedback
Reflection (Meijer et al., 2006; Molenaar & Chiu, 2014; Moreno & Mayer, 2007; Pintrich, 2000; Zimmerman, 2003)	Knowledge acquisition (Bannert & Reimann, 2012)	What did you learn from this problem?	Short Answer Text Entry Box Audio Input Notes	
	Knowledge transfer (Lin, Newby, & Foster,1994; Liu, Horton, Toprac, & Yuen, 2012; Kirkley, 2003)	Can you think of other settings where those skills could be applied?	Short Answer Text Entry Box Audio Input Notes	
	Present alternative solutions (Ge & Land, 2003, 2004)	What are other solutions? Why didn't choose them?	Short Answer Text Entry Box Audio Input Notes	
	Identify pros and cons of proposed solution (Ge & Land, 2004)	What are the pros and cons of the chosen solution? (Bulu & Pedersen, 2010; Ge & Land, 2004)	Short Answer Text Entry Box Audio Input Notes	

CHAPTER 5: RESULTS

This chapter discusses findings from the expert review of the proposed framework for creating metacognitive scaffolds in solving ill-structured problems. It addresses reviewers' feedback and presents revisions accordingly. The revised framework is presented in Appendix A. In Design and Development research, expert review is conducted to evaluate and improve a model or design principles (Richey & Klein, 2007). In this research, a pilot study was carried out to ensure the readability of the framework and estimate the time it takes to evaluate the framework.

Findings

To evaluate and improve the proposed framework, scholars who specialize in instructional design, problem solving, and metacognition were invited to review the framework. In the end, three scholars with relevant expertise participated in this study. Prior to the expert review phase, two scholar-practitioners: Dr. Deyu Hu and Dr. Eunice Ofori took part in the pilot study. Dr. Deyu Hu is the Associate Director of Research Training and Special Initiatives at Virginia Tech. Dr. Eunice Ofori is the Instructional Designer at the Technology-enhanced Learning and Online Strategies at Virginia Tech. Their feedback was helpful for the researcher to improve the content. Once the revision of the framework was completed, it was sent to the experts for formal review. Feedback from the experts was collected via an online survey that includes multiple-choice and open-ended questions. The three experts are:

- Dr. Xun Ge, Professor of Instructional Psychology and Technology at the University of Oklahoma. Dr. Ge's primary research interest involves scaffolding students' complex and ill-structured problem solving and self-regulated learning through designing instructional scaffolds, cognitive tools, learning technologies, and open learning environments. She is currently the Chair for the Problem-based Education Special Interest Group for the American Educational Research Association and President-Elect of Association for Educational Communications and Technology.

- Dr. Chwee Beng Lee, Associate Professor of Secondary Education and Director of Higher Degree Research, Research and Higher Degree at Western Sydney University. Dr. Lee has published extensively in problem solving, learning technologies, and instructional Design.
- Dr. Brett D. Jones, Professor of Educational Psychology at Virginia Tech. Dr. Jones' research includes investigating how students' beliefs impact their motivation, and examining methods instructors can use to design instructional environments that support students' motivation and learning.

Overall, these experts provided positive feedback about the proposed framework supporting its validation for use. As one reviewer said: "The main processes and components of ill-structured problem solving have been identified, so were the instructional strategies. The instructional strategies identified and summarized from the literature review are helpful, particularly with the support of examples." However, they also provided suggestions for improvement. By reviewing the feedback from the expert reviewers, two major content areas needed to be improved, which are media types and feedback.

Media Types

The reviewers pointed out that ill-structured problem-solving is a reflective and iterative process, media types proposed in the framework are insufficient to support metacognitive development in solving ill-structured problems.

Reviewer One said:

"The functions (True/false, checkbox, radio buttons, short text entry, etc.) were insufficient to scaffold learners in solving complex and ill-structured problems. Those can be used as the beginning of a conversation, perhaps, to draw more conversations as in a decision tree, step by step, leading learners in deeper reflective cycle of conversations."

Reviewer Two reported:

"Ill-structured problems differ in their structuredness, complexities and dynamicity. As such, multiple representations are needed. You have a range of interactive media types which may help participants to build multiple representations, but they may be too simplistic for solving ill-structured problems. For instance, when solving a pollution problem which is highly ill-structured (bear in mind that it is very dynamic), the current interactive media types you have may not be sufficient to support the instructional strategies. For solving pollution (or relevant type of problem), participants need to examine and understand the constraints of it, the complexities involve and how dynamic the problem is. I recommend that you consider media type that can better support the instructional strategies."

To address the concern related to using media that are more appropriate to scaffold metacognition, the researcher explored the possibilities of adding web-based applications into the e-Learning content. It was found that the Web Objects function in e-Learning authoring tools would allow the insertion of web-based applications ("Storyline 360: Adding Web Objects," n.d.; "Insert web objects," n.d.). Those web-based applications can be added by typing the web address, upload web content from local computer ("Storyline 360: Adding Web Objects," n.d.), or embed code using Web Objects ("Insert web objects," n.d.). To address expert reviewers' feedback, three web applications are added to the framework, which are chatbot, discussion forum, and AI - based feedback system. Chatbot offers continuous scaffolds to learners during the problem-solving process. Discussion forum provides an online environment for learners to exchange thoughts with their peers and instructor, which fosters reflective and deep learning. AI-based feedback system generates contextualized feedback for each question learner answers. Therefore, the following paragraph that describes these three web-based applications was added to the framework.

Web objects. Web objects that include AI-based feedback systems, discussion forums, and chatbots can be added to e-Learning content. AI-based feedback system grades students' responses using machine learning methods and provides contextualized feedback immediately (Chen, 2004; Warschauer & Grimes, 2008). It supports metacognitive scaffolding with helping learners evaluate and reflect on their thinking processes. To promote reflective thinking, discussion forum could also be added to support peer interaction. Pedro, Abodeeb-Gentile and Courtney (2012) viewed discussion forum as an effective media to train metacognition. Peer feedback helps learners evaluate and revise their own responses (Ertmer et al., 2007; Van der Pol, Van den Berg, Admiraal, & Simons, 2008). In addition to integrating discussion forum in online materials, chatbot could also be integrated to provide timely assistance to the learner. Chatbot is known as conversational agent (Kerry, Ellis, & Bull, 2008; Griol, Molina, & de Miguel, 2014; Roda, Angehrn, & Nabeth, 2001), or personal coach (Roda et al., 2001). It is an artificial intelligence application that implements natural language processing techniques to answer learners' questions (Clarizia, Colace, Lombardi, Pascale, & Santaniello, 2018; Kerry et al., 2008). Research showed that chatbot helped learners develop self-regulation skills in problem-solving contexts (Beaumont, 2012).

Another area for improvement suggested by the experts is feedback. They think that some feedback provided in this framework is not helpful in terms of engaging learners in metacognitive processing and deep learning.

Feedback

The reviewers mentioned that the feedback presented in the framework should be more specific and contextualized. They all pointed out that when learner answers "No", the given feedback is not enough to foster metacognition. As Reviewer One said: "The feedback should be more specific and contextualized. It would not work if prompted to go back just to review the materials."

Reviewer One also commented on the design of the feedback:

> "The feedback for "Yes" is okay, but for those students who answer "No", instead of providing further scaffolding through prompting or explanations, the students were asked to review the notes or pay attention to highlighted words, which would NOT work to help them engage in deep cognitive and metacognitive processing."

Reviewer Two said:

"By directing participants to study the lecture slides if answered "No", may not necessarily help to support planning". Reviewer two further commented: ""Good job" "Great" are poor feedback as they do not foster thinking. Good/Constructive feedback is on that generate deep thinking."

Reviewer Three stated:

"I agree that it's pretty generic in that it could relate to many different disciplines. The downside of that is that the system feedback isn't overly helpful. Telling a student to go back and review again or go back and try again isn't very helpful, they probably need more specific feedback."

Reviewer Three also identified specific examples in the framework that need to be refined. For instance:

- "For "Identify relevant and irrelevant information," media types are short answer and text entry. If the student provides one of these, how will the system give the learner an error message immediately? This would require a human to read it and then give that feedback. I was thinking that this system feedback would be done by the computer automatically."
- "For "Are you reaching your goals" it seems in appropriate to say "Keep working" if they say "no" because it might be that they're working hard, but can't find a good strategy. Maybe it should has what problems they are having in working towards their goals. For "Have you taken into account the perspectives of different stakeholders" if the learner answers no isn't it possible to tell them that they need to take those perspectives into account? Maybe they just needed to be reminded. They wouldn't

necessarily have to rework the problem, they might just need to revise it or consider it. Maybe it's just the word "reword" that is not necessarily always what they need to do.”

To address the reviewers’ comments, the researcher pursued ways to include contextualized feedback in the framework. Contextualized feedback can be offered by either the instructor, peers or AI-based grading system. The following paragraphs that describe contextualized feedback with focusing on AI-based feedback system were added to the framework.

In discussion forum, learners can interact with their peers and instructor to provide contextualized feedback to each other. However, due to the asynchronous nature of communication in discussion forum, feedback may be given with delay. In comparison to instructor and peer feedback, AI - based technologies provide instant feedback and save the manual labor of grading (Chen, 2004; Warchauer & Grimes, 2008). It has been used in educational environments to give contextualized and continuous feedback to learners (Chen, 2004; Warschauer & Grimes, 2008). For instance, Wang, Chang and Li (2008) implemented automated grading of open-ended questions in science learning.

In alignment with Wang et al. (2008)’s idea to grade open-ended questions automatically. Open-ended questions in e-Learning materials could also be evaluated using AI techniques. AI techniques, such as natural language processing, have been used to develop automated writing evaluation (AWE) systems to assess students’ essays (Dikli & Bleyle, 2014; Li, Link, & Hegelheimer, 2015). Automated feedback was found helpful to support learners with reflecting on and improving their writings. Several AWE systems also provide continued feedback for learners and allow iterative revisions of learner responses (Chen, 2004; Warschauer & Grimes, 2008). The implementation of AI-based feedback systems in e-Learning could play an important role in supporting learners with developing metacognitive strategies, such as evaluating and reflecting.

In addition to commenting on content of the framework, the reviewers also pointed out several grammar issues. As Reviewer Three suggested: "Make the words all consistent. So, if they end in "ing" they should all end that way, like orienting, planning, monitoring, evaluating, reflecting". Same thing in Figure 1 where it should be "represent problem"." Reviewer Three also recommended revising the Metacognition-based Ill-structured Problem-solving Process:

> "It took me a while to figure out that there could be more than one strategy in each of the problem stages. You could fix this adding the metacognitive strategies into Figure 1, underneath them or something so that it was clear that the strategies are used in a few different problem solving stages."

Modifications were made throughout the framework based on the reviewers' feedback, and the refined framework is presented in Appendix A. Metacognitive strategies were added underneath each problem-solving stage to make the framework clear and easy to understand, and the changes are reflected in Figure 6.

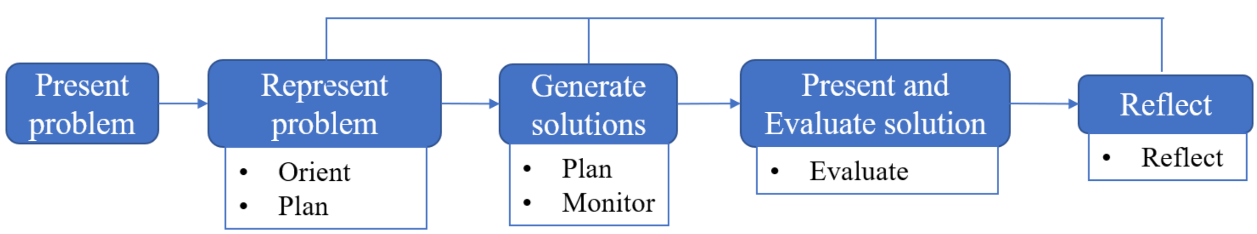

Figure 6. Revised Metacognition-based Ill-structured Problem-solving Process

Furthermore, reviewers mistook feedback for exemplar questions presented in the framework as general feedback, which was in part caused by the separation of exemplar questions and feedback. Therefore, the researcher re-organized and incorporated the exemplar questions and feedback columns to enhance its readability. Changes are reflected in the tables in Appendix A. In the end, one reviewer recommended that this study should be contextualized with focusing on one-two types of ill-structured problems. However, this study is Type II Design and Development research - model research (Richey et al., 2004; Richey & Klein, 2007; Richey & Klein, 2014), the findings are intent to provide generalizable instead of context-specific guidance (Type I). This design framework consists of a wide range of instructional design strategies and media from which practitioners can choose to use for specific design case or context.

CHAPTER 6: DISCUSSION

This chapter presents a summary of the study, theoretical and practical implications, and recommendations for future research. This study advances the field of the instructional design by proposing an innovative framework to guide the design of computer-based metacognitive scaffolds in ill-structured problem-solving curriculums.

Summary of the study

Problem-solving has been studied extensively in many disciplines (Jonassen, 2011; Lazonder & Rouet, 2008; Lester, 1994; Pappas, 2002; Wilson et al., 1993), however, it did not receive much attention in the field of instructional design (Jonassen, 2000, 2011). Given the importance of solving ill-structured problems in daily lives, there is a need to create effective instruction to teach such skills. Metacognition is regarded as key to solving ill-structured problems (Lin et al., 1999; Jonassen, 2000). Therefore, metacognitive scaffolds can be integrated into computer-based curriculums to teach problem-solving skills. This study seeks to develop an interactive content design framework to guide the design of ill-structured problem-solving instruction using e-Learning authoring tools.

By implementing Type II – design and developmental research method, a framework is created for instructional designers, instructors, and other key stakeholders to use to develop computer-based ill-structured problem-solving instruction. Type II design and developmental research is model research (Richey & Klein, 2007, 2014), which aims to create conceptual and procedural models to guide instructional design processes (Richey & Morrison, 2010; Ross et al., 2007). This study consists of several major steps. Firstly, an initial framework was proposed based on existing literature and e-

Learning practices, including research articles and practical guidelines. According to Richey and Nelson (1996), literature from practical reports can be used in innovative developmental studies when research literature is scarce. Secondly, scholars who specialize in instructional design, problem-solving, and metacognition were invited to review the framework. Finally, the researcher revised the framework based on reviewers' feedback. The completed framework is descriptive, comprehensive, and generalizable. It contains metacognitive strategies, instructional strategies, media attributes, and instructional activities from which practitioners could choose to use in various design cases.

Contribution of the Study

The rapid growth of technology infuses the development of computer-based instruction that has been widely used in education and organizational training (Haghshenas et al., 2012; Johnson & Rubin, 2011). A large number of computer-based instruction was created using e-Learning authoring tools. Those authoring tools allow the integration of multimedia (Diwakar, Patwardhan, & Murthy, 2012) to produce computer-based instruction that can run on all platforms (Shukla & Pal, 2015). Given the importance of ill-structured problem-solving instruction, this study explores the interactivity across a variety of e-Learning authoring tools to develop such content. This study makes several contributions to the field of instructional design and technology. Firstly, it bridges the gap between theory and practice by proposing a theory-based framework to guide instructional design practices. Secondly, it highlights the importance for designing ill-structured problem-solving curriculums in the field of instructional design. Thirdly, it provides detailed instructions for practitioners to create computer-based metacognitive scaffolds using e-Learning authoring tools. Lastly, this framework adopts the type II design and developmental research method that produces generalizable findings (Richey et al., 2004; Richey & Klein, 2007, 2014). It serves as a guide for designing computer-based ill-structured problem-solving curriculums in various disciplines. The following sections elaborate on its theoretical and practical implications.

Theoretical implication. The proposed framework is based on constructivism that emphasizes on the interaction between learner and learning environment (Rieber, 1992). Constructivism posits that knowledge is constructed based on one's past experience, and purposeful design of learning environment could facilitate the knowledge construction process (Jonassen, 1994). Constructivist learning environment is learner-centered (Jonassen, 1994; Wang, 2009), computer-based (Oliver & Herrington, 2003; Wang, 2009), contextualized (Jonassen, 1994; Oliver & Herrington, 2003; Savery & Duffy, 1995), and it provides scaffolding (Dalgarno, 2001) and supports reflective thinking and collaboration (Jonassen, 1994; Oliver & Herrington, 2003). Constructivism problem-based learning environment supports learner in developing metacognitive skills with scaffolding (Savery & Duffy, 1995). In this framework, scaffolds in the computer-based learning environment are created using e-Learning authoring tools.

This study makes several theoretical contributions. Firstly, it adds to the existing literature by presenting a comprehensive conceptual and procedural model to guide the design of computer-based metacognitive scaffolds in ill-structured problem-solving learning environment. By implementing a design and developmental research approach, the researcher went through a rigorous design process by first synthesizing literature in ill-structured problem-solving, metacognition, computer-based instruction, and multimedia design to propose a design framework, and then invited experts to review the framework for validation purposes.

Secondly, it could contribute to knowledge related to media research with focusing on the usage of media attributes to create effective instructional materials. For the past decades, media comparison study was prevalent that sought to find out whether one media is better than the other. However, numerous studies proved no difference in learning outcomes when using different media to deliver instruction. In recent years, more research has been conducted to study the affordances of social media on collaborative learning (Jeong & Hmelo-Silver, 2016; Tay & Allen, 2011). Those technologies allow learners to monitor and regulate their collaborative learning process (Jeong & Hmelo-Silver, 2016). Rather than replicating media comparison research, this study provides guidelines on creating interactive learning content with utilizing various media types in e-Learning authoring tools to foster individual as well as collaborative learning. For instance, instead of trying to show whether video instruction is better than audio instruction, those media could be added to e-Learning materials to present content or provide feedback to learners based on learning needs and learner's media preference.

Thirdly, it documents the process of carrying out a design and developmental research project, which can be used by researchers who are interested in replicating or continuing this study. Additionally, it informs the value of model research that produces a generalizable framework to guide the design of computer-based metacognitive scaffolds in various disciplines. Otherwise, it would be challenging to create such an innovative framework with utilizing other research methods when taking many design variables and procedures into consideration.

Practical implication. A major purpose of this framework is to provide guidelines for practitioners to use when designing metacognitive scaffolds in ill-structured problem-solving instruction. By following the guidelines, instructional designers, instructors and other key stakeholders can develop standalone, computer-based, interactive learning materials for learners to access regardless of time and location. Those guidelines are not domain specific, which can be used to design interactive content using e-Learning authoring tools in various domains. This framework is inclusive of metacognitive strategies, instructional strategies, and media attributes. Practitioners can choose the most relevant ones to create computer-based metacognitive scaffolds. Metacognitive scaffolds are effective tools that support metacognitive development in solving ill-structured problems (Bulu & Pedersen, 2010; Ge & Land, 2003). Question prompts and expert modeling are effective metacognitive scaffolds to guide learners during problem-solving process (Belland et al., 2008; Ge & Land, 2003; Hollingworth & McLoughlin, 2001; Lin et al., 1999). Examples of metacognitive scaffolds presented in this framework include question prompts, expert scaffolding, and feedback.

A variety of interactive media types in e-Learning authoring tools can be used to create metacognitive scaffolds. Those interactive media types include Text Box, Short Answer, True/False, Multiple Choice, Checkbox, Radio Button, Hyperlinks, Audio Input, and Animation ("Articulate Storyline," 2012; "Captivate User Guide," n.d.). Course designers and developers could choose from those media types for interaction planning and decision-making in authentic design contexts. Expert reviewers suggested adding more media types to support reflective and iterative ill-structured problem-solving process. With taking those experts' feedback into consideration, AI-based feedback systems, discussion forums, and chatbots are added via web objects function in e-Learning authoring tools to produce computer-based metacognitive scaffolds.

Feedback is essential to foster metacognitive development in computer-based learning environment (Lee, Lim, & Grabowski, 2009, 2010). According to expert reviewers, feedback should be contextualized in ill-structured problem-solving instruction. Thus, practitioners need to dive deep into the media attributes of e-Learning authoring tools and integrate external web applications if needed to offer contextualized feedback based on learner responses. For instance, AI-based feedback system can be added as a web object, which grades learners' answers and provide immediate contextualized feedback (Chen, 2004; Warschauer & Grimes, 2008). Other web objects include discussion forum and chatbot. Discussion forum is an effective media to train metacognition where the learner can receive feedback and continue discussions with the instructor and their peers (Ertmer et al., 2007; Pedro et al., 2012; Van der Pol et al., 2008). Chatbot is an artificial intelligent application (Clarizia et al., 2018; Kerry et al., 2008) that helps learner develop self-regulation skills via conversation exchange (Beaumont, 2012).

However, it may require collaborative efforts to develop a web-based application that generates contextualized feedback. To do so, the instructional designer needs to work with the subject matter expert(s) and web developer(s) to build an effective machine learning application. It may take time to collect preliminary data and train the algorithm to generate effective and accurate feedback. According to Nguyen (2019), building a chatbot requires careful response planning with the continuous development process. If such a team cannot be formed, an existing AI application can be integrated into the computer-based curriculum. However, many of the existing chatbots were built for use in certain domains. For instance, Mandy, a medical chatbot that was created to collect patient input and submit reports to the doctors (Ni, Lu, Liu, & Liu, 2017); MILABOT was built to have conversations with human beings on popular topics (Serban et al., 2017). Therefore, it may be difficult to find an existing chatbot for a specific ill-structured problem domain.

Recommendation for Future Research

This study is type II design and developmental research – model research. Model research contains model development, model validation, and model use (Ross et al., 2007). In this study, model development was completed by proposing a computer-based metacognitive scaffolds design framework, whereas model validation was conducted by inviting experts to review the framework. The next steps for this study are to validate the framework empirically and deploy this framework for use. According to Richey and Morrison (2010), data collected from empirical research not only verifies the framework, but also shows how it works. Therefore, instructional designers, instructors and other practitioners will be invited to design metacognitive-based ill-structured problem-solving curriculums by following the proposed guidelines. Case study, field observation, interview, and survey (Ross et al., 2007) can be used to collect data to empirically validate the framework. The following step would be to deploy the ill-structured problem-solving curriculums with learners. By doing so, the framework will be further validated and improved based on learners' feedback.

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Appendix A: Framework for Designing Metacognitive Scaffolds in Ill-structured Problem-Solving Instruction Using eLearning Authoring Tools

This chapter presents a descriptive framework for designing metacognitive scaffolds in ill-structured problem-solving instruction using eLearning authoring tools. It first introduces metacognitive scaffolds and problem space, and then describes ill-structured problem-solving stages, metacognitive strategies, instructional activities, and media attributes and examples. Tables that include those key attributes are added to the end of this chapter. This framework serves as instructional guidelines for instructional designers, instructors, and practitioners to design metacognitive scaffolds in various ill-structured problem-solving contexts. Metacognition plays an important role in problem solving, especially in solving ill-structured problems, as it guides the learner to plan, monitor and evaluate their thinking process (Davidson et al., 1994; Ge & Land, 2003, 2004; Gordon, 1996; Jonassen, 2000; King, 1991; Lin, 1994; Lin et al., & Secules,1999). Researchers have implemented metacognitive scaffolds in instructional activities (Bulu & Pedersen, 2010; Ge & Land, 2003; Liu, Horton, Toprac, & Yuen, 2012) and found that metacognitive intervention could lead to improved learner performance (Ge & Land, 2003, 2004; Tzohar-Rozen & Kramarski, 2014).

Commonly used metacognitive scaffolds in problem solving instruction include prompting and modeling (Belland, Glazewski, & Richardson, 2008; Ge & Land, 2003; Hollingworth & McLoughlin, 2001; Lin et al., 1999). Question prompts helped learner externalize, monitor and understand their thinking processes (Lin et al., 1999; Lin & Lehman, 1999), which could enhance their metacognitive awareness (Hollingworth & McLoughlin, 2001). Expert modeling was often presented in video demonstration, animation or simulation (Hollingworth & McLoughlin, 2001; Lin et al.,1999; Pedersen & Liu, 2002). According to the Zone of Proximal Development, novice learners expand their knowledge with the assistance from more advanced peers or teachers (Vygotsky, 1986). In a computer-based learning environment, interactive content could play the role of an expert or capable peer who assists less competent learners to achieve the learning goals that they won't be able to accomplish on their own. The "expert" in a hypermedia program can be a mediated character that demonstrates the problem-solving process (Pedersen & Liu, 2002) or a conversation agent that provides continued scaffolding for the learners (Kerry, Ellis, & Bull, 2008; Griol, Molina, & de Miguel, 2014; Roda, Angehrn, & Nabeth, 2001),

Scholars believe that a continuum exists between ill-structured and well-structured problems, and there is no clear boundary between them (Simon, 1973; Voss, 1988). Ill-structured and well-structured problems share similar problem-solving procedures (Gick, 1986), such as represent the problem, generate solutions, present a solution, evaluation and reflection. This framework presents detailed instruction to guide the design of metacognitive scaffolds that facilitate learners in solving ill-structured problems. Designers, instructors, and other stakeholders could use this framework to design problem-based interactive learning materials using eLearning authoring tools, such as Adobe Captivate, Articulate Storyline, and Lectora. The interactive content allows the learner to control the pace of learning and access the materials regardless of time and location, as well as provides learner with instant feedback that increases learner motivation (Lin, 1994; Jones, 2009; Jones, Paretti, Hein, & Knott, 2010). The following sections introduce problem space and key problem-solving stages and describes relevant metacognitive scaffolds, instructional strategies, examples, and interactive media types in each stage identified from existing literature. Those literature consists of research papers, book chapters, thesis and dissertations, as well as practical guidelines.

Problem Space

Constructing a problem space is essential for solving an ill-structured problem (Jonassen, 2000). Problem space refers to the space or internal environment that contains all variables, goals, constraints, paths and stages in transforming the current state of a problem to its ideal state (Newell & Simon, 1972; Voss, 1988). There are no algorithms or rules to follow to solve ill-structured problems as those that would be used for solving well-structured problems (Jonassen, 1997, 2000). Learners need to consider various paths, stages and solutions in a problem space (Jonassen, 1997, 2000). This may seem challenging for novice learners, therefore, Jonassen (2000) urged designers to construct problem space for learners, especially for beginners. By implementing appropriate metacognitive scaffolds (e.g. question prompts) in the learning content, the computer-based instruction could help learners construct problem space and guide them through the ill-structured problem-solving process.

Ill-structured Problem-solving Stages

Ill-structured problem-solving instruction can be created with following general ill-structured problem-solving procedures. Those stages contain represent problem (Belland et al., 2008; Ge & Land, 2003; Kale et al., 2018; Sinnott, 1989; Swanson, 1990), generate solutions (Belland et al., 2008; Chi & Glaser, 1985; Ge & Land, 2004; Sinnott, 1989), present a solution (Belland et al., 2008; Ge & Land, 2003, 2004), evaluate (Davidson, Deuser, & Sternberg, 1994; Ge & Land, 2003, 2004; Lin, Newby, Glenn, &

Foster, 1994; Jonassen, 1997), and reflect (Kauffman, Ge, Xie, & Chen, 2008; Kim & Hannafin, 2011). Related literature is listed in Table 7.

Table 7

Revised Ill-structured problem-solving stages

Stages	**Literature**
Represent problem	Decide about the essence or nature of the problem (Sinnott, 1989); Define, generate and pursue learning issues to understand the problem (Belland et al., 2008); Understand a situation, information, main features/mechanism (Kale et al., 2018); Presentation, understanding, or definition of problem (Swanson, 1990); Problem representation (Ge & Land, 2003).
Generate solutions	Develop a possible solution ((Belland et al., 2008); Search for a solution (Chi & Glaser, 1985); Choose and generate solutions (Sinnott, 1989); Solution development (Ge & Land, 2004).
Present and evaluate solution	Present their solution and the evidence to support it (Belland et al., 2008); Provide justifications (Ge & Land, 2003, 2004); Monitor and evaluation (Ge & Land, 2003, 2004); Solution evaluation (Davidson et al., 1994); Evaluate (Lin et al., 1994); Assess problem solution (Jonassen, 1997).
Reflect	Reflection and negotiation (Kim & Hannafin, 2011); Reflect on work (Kauffman et al., 2008).

Different from well-structured problem solving, ill-structured problem-solving procedures are not linear but rather situated (Jonassen, 1997, 2000; Voss, 1988), dynamically intertwined, circular, and iterative (Ge, Law, & Huang, 2016) as seen in Figure 6. For example, the entire process of playing chess is defined as solving an ill-structured problem (Simon, 1973), however, the player needs to redefine the problem space and regenerate solutions after each move. Some scholars also viewed ill-structured problem-solving process as a design process (Ge & Land, 2003, 2004; Jonassen, 1997, 2000), examples of ill-structured problems may include designing a house or proposing a plan to reduce air pollution.

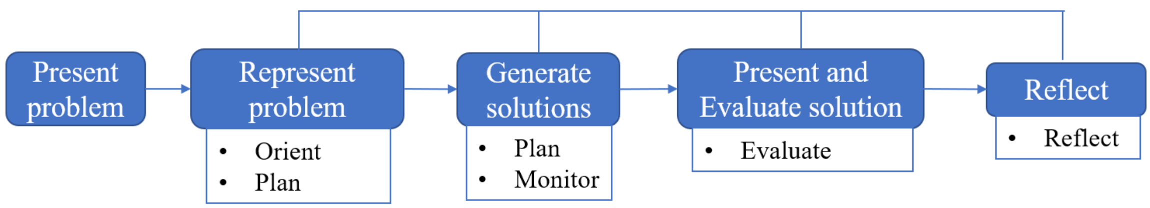

Figure 6. Revised Metacognition-based Ill-structured Problem-solving Process

The initial stage of creating metacognitive-based ill-structured problem-solving instruction is to present the problem. Problems presented in the learning materials should be situated and real-world problems that could foster the transfer of knowledge (Lin et al., 1994; Liu et al., 2012; Park & Hannafin, 1993). It also helps the learner apply the acquired knowledge and skills in other contexts (Liu et al., 2012). Once an ill-structured problem is presented, learner can follow the problem-solving stages to solve the problem. The stages include represent problem, generate solutions, present and evaluate a solution, and reflect.

Represent problem. A problem appears ill-structured if the problem statement is vague with no specified goals or constraints (Chi & Glaser, 1985; Jonassen, 1997; Shin et al., 2003; Voss, 1988). The problems and goals are not measurable or predictable, and approaches to reach the goals also vary from case to case. The purpose of problem representation is to understand and form the initial state of the problem (Voss, 1988), such as identifying cause(s) of the problem and setting goals. This process is complex, which requires the learner to discover missing information, differentiate relevant information from irrelevant information, and express personal opinions of the problem

(Jonassen, 1997, 2000). To assist learner with developing a problem representation, metacognitive scaffolds could be created to facilitate learner with identifying all causes, constraints of a problem (Ge & Land, 2003; Jonassen, 1997; Voss, 1988), as well as various solution paths (Jonassen, 1997).

Instead of using general rules or principles, schemata are vital for interpreting new problems in ill-structured problem scenarios (Chi & Glaser, 1985; Ge & Land, 2004). Schemata are mental structures that represent relationships and connections between objects, events and contexts in long-term memory (Chi & Glaser, 1985; Gick, 1986). Each scheme contains information (e.g. goals, constraints, and procedures) related to a certain problem type (Gick, 1986; Jonassen, 2000), and they are formed based on one's past experiences (Gick, 1986; Jonassen, 1997, 2000). If a problem seems familiar, pertinent scheme will be activated (Chi & Glaser, 1985; Gick, 1986), learner can skip the solution generation stage and proceed to present solution stage directly. Otherwise, a general problem-solving procedure will be activated to guide the learner to search for appropriate strategies to solve the problem (Chi & Glaser, 1985).

Generate solutions. Once the initial state of an ill-structured problem is constructed, learner moves on to generate solutions. According to Shin et al. (2003), ill-structured problem could possess more than one solution with multiple solution paths. Jonassen (1997) viewed that multiple solutions resulted from different problem representations. He also stated that a solution was chosen based on the solver's view of the causes and constraints of a problem. Sinnott (1989) named this process as creative exercises, which cultivates divergent thinking.

In this stage, learner needs to develop possible solutions with supporting evidence

(Belland et al., 2008), which requires and fosters argumentation skills. Belland et al. (2008) asserted that argumentation is key to solving ill-structured problems. For each argument the learner makes, evidence is needed to support the claims. This process requires information identification, strategy selection, data collection and action plan formulation. In addition to considering various solutions and solution paths, criteria for evaluating the solutions also need to be proposed (Shin et al., 2003; Swanson, 1990).

Present and evaluate solution. Once a solution is chosen, it will be verified and evaluated (Garofalo & Lester, 1985; Kwang, 2000). Huttenlock (2007) suggested to evaluate both the process and goal completion in an ill-structured problem domain. The evaluation of goal completion focuses on checking if they have enough information to confirm their claims or reach the preset goals, whereas, process evaluation emphasizes on choosing appropriate data and strategy during the process (Huttenlock, 2007). Jonassen (1997) proposed to evaluate the viability of solutions by asking questions, such as "Was the problem solved? Did it adhere to the constraints?". As ill-structured problems have divergent solutions, it is critical for learners to justify their decisions by explaining why the chosen solution would work (Belland et al., 2008; Bulu & Pedersen, 2010; Lin & Lehman, 1999; Shin et al., 2003).

In addition to justifying the solution, scholars also recommended to evaluate the supporting evidence and information (Bulu & Pedersen, 2010), check with evaluation criteria (Jonassen, 1997; Swanson, 1990), and identify side effects (Ge & Land, 2004; Simon, 1973) in this stage.

Reflect. Reflection is the last stage in ill-structured problem-solving process. During this stage, learner revisits ideas, process, adopted strategies, and solutions

(Collins & Brown, 1987; Kim & Hannafin, 2011). Learning occurs when learner reflects on their own mistakes and plans for improvement and knowledge transfer in other contexts. Collins and Brown (1987) also stated that computer could be used as an effective medium to facilitate the reflection process by recording and presenting thinking process.

Metacognitive Strategies and Instructional Activities

Metacognitive strategies are vital for solving ill-structured problems by monitoring and controlling cognitive processes (Brown et al., 1994; Efklides, 2008; Flavell, 1987). They are used in the problem-solving process by planning tasks, selecting cognitive strategies, and making revision (Akturk & Sahin, 2011; Paris & Winograd, 1990). According to Shin et al. (2003), metacognitive skills, such as plan and monitor are strong predictors of the success in solving unfamiliar ill-structured problems. Five metacognitive strategies are presented in this framework, which are Orient (Bannert & Reimann, 2012; Garofalo & Lester,1985; Meijer, Veenman, & van Hout-Wolters, 2006; Molenaar & Chiu, 2014), Plan (Brown, 1987; Gordon, 1996; King, 1991; Kirsh, 2005; Molenaar & Chiu, 2014; Pintrich, 2002; Shin, Jonassen et al., 2003; Zimmerman, 2003), Monitor (Brown, 1987; Efklide, 2014; Gordon, 1996; King, 1991; Kirsh, 2005; Pintrich, 2000; Zimmerman, 2003), Evaluate (Bannert & Reimann, 2012; Brown, 1987; Gordon, 1996; Meijer et al., 2006; Molenaar & Chiu, 2014; Schmidt & Ford, 2003; Yıldız-Feyzioğlu et al., 2013), and Reflect (Meijer et al., 2006; Molenaar & Chiu, 2014; Moreno & Mayer, 2007; Pintrich, 2000; Zimmerman, 2003).

Instructional scaffolds could be used to support those metacognitive strategies in solving ill-structured problems (Ge & Land, 2003, 2004). This section introduces metacognitive strategies and relevant instructional scaffolds that could be created using eLearning authoring tools. Scaffolds consist of two categories: question prompts and expert modeling. In addition to regulating learners' thinking processes, this framework also introduces scaffolds that help learners raise metacognitive awareness (e.g. ease of learning) and help them cope with negative emotions. Pekrun, Goetz, Titz and Perry (2002) stated that difficulty encountered in resolving academic problems may cause anxiety that hinders motivation, whereas appropriate emotion scaffolding could enhance learner motivation (Kim & Pekrun, 2014). Emotion regulation scaffolds can be created using question prompts, such as "Is this problem easy or hard?", which is shown in Table 8. If learner indicates that this problem is very hard, expert modeling will be provided to assist learner with solving the problem and sustain learner motivation.

Orient. Garofalo and Lester (1985) defined orienting as a strategic behavior to understand and assess a problem. Meijer et al. (2006) asserted that experts spent more time than beginners on orientation activities. Orienting occurs during problem representation stage, and orienting activities include understand the problem (Belland et al., 2008; Kale et al., 2018), examine causes of the problem (Jonassen, 1997; Kauffman, Ge, Xie, & Chen, 2008; Voss, 1988), identify relevant and irrelevant information (Hollingworth & McLoughlin, 2001; Swanson, 1990) as well as constraints, variables, and relations (Ge & Land, 2004; Kale et al., 2018; Voss, 1988).

Orienting skills could be trained using question prompts in computer-based instruction, such as "What are the causes of the problem?" (Kauffman et al., 2008), "What information is relevant to solve this problem and what information is irrelevant?" (King, 1991), and "What are the key variables of this problem and how are they related?"

(Meijer et al., 2006). More examples can be seen in Table 8.

Plan. Tzohar-Rozen and Kramarski (2014) defined planning as a skill of choosing strategies and allocating resources. It is applied in problem representation and generating solutions stages. In problem representation stage, planning activities include activating prior knowledge and experience (Huttenlock, 2007; Meijer et al., 2006; Shahbodin & Bakar, 2010; Yıldız-Feyzioğlu, Akpınar, & Tatar, 2013), setting goals (Bannert & Reimann, 2012; Garofalo & Lester, 1985; Yıldız-Feyzioğlu et al., 2013), and formulating hypothesis (Bogard, Liu, & Chiang, 2013; Gick, 1986; Meijer et al., 2006; Swanson, 1990). During the solution generation phase, planning activities contain formulating action plan (Huttenlock, 2007; Kapa, 2001; Meijer et al., 2006), identifying needed information (Bulu & Pedersen, 2010; Huttenlock, 2007; Swanson, 1990), and selecting strategy (Huttenlock, 2007). Learning resources could be integrated into the eLearning content to assist learner with locating information and setting goals.

Planning scaffolds can be designed as question prompts, such as "Do you have any related experience with this kind of problem?" (Shahbodin & Bakar, 2010), "What are possible solutions of this problem?" (Ge & Land, 2003; Shahbodin & Bakar, 2010), "What are the steps to solve this problem?" (Hollingworth & McLoughlin, 2001; Shahbodin & Bakar, 2010). When a True/False or Multiple Choice question is used to design a question prompt, pertinent system feedback will be provided based on learner's response, such as providing cues or hints when learner answers the question incorrectly. More information on planning scaffolds and examples can be found in Table 8 and Table 9.

Monitor. Monitor refers to one's awareness of task comprehension and performance (Schraw, 1998; Tzohar-Rozen & Kramarski, 2014). Quintana, Zhang and Krajcik (2005) described monitoring activities as identifying tasks, evaluating work progress and predicting outcomes. Monitoring occurs throughout the problem-solving process, which includes the monitoring of cognitive process and learner emotion. Monitoring emotion consists of the monitoring of feelings and judgement, which relates to the awareness of metacognitive experiences (Efklides, 2014). It is through the monitoring of metacognitive experiences that the learner adjusts their actions in the problem-solving process, e.g. initiate or terminate tasks (Efklides, 2014).

Examples of monitoring prompts include “Is this problem easy or hard?” (Tzohar-Rozen & Kramarski, 2014), “Are you reaching your goals?” (Huttenlock, 2007), and “Are you using the strategy that you chose?” (Kwang, 2000). Appropriate system feedback will be provided based on learner’s response to each question. In addition, expert modeling will be offered when learner expresses difficulties in completing tasks. Expert modeling can be presented in video demonstration or simulation learning environment. More monitoring scaffolds and examples can be found in Table 9.

Evaluate. Evaluation strategies are used in the evaluation stage of solving ill-structured problems, which serves the purpose to justify proposed solution and process (Tzohar-Rozen & Kramarski, 2014). Metacognitive scaffolds adopted in this phase are specified as the assessment of supporting information (Bulu & Pedersen, 2010) and defending of a chosen solution (Ge & Land, 2004). However, if the chosen strategy does not meet the evaluation criteria, learner needs to restart the problem-solving process. It is through evaluation that the learner refines their working process and outcomes. Question prompts that are used to foster metacognitive evaluation can be presented as “What are your reasons and/or arguments for proposing this solution?" (Ge & Land, 2003) and "Have you taken into account the perspectives of different stakeholders?" (Ge & Land, 2004). More related strategies and examples are described in Table 10.

Reflect. Designing metacognitive scaffolds to facilitate learner reflection is the last stage in creating computer-based ill-structured problem-solving instruction. Reflection is a metacognitive strategy (Meijer et al., 2006; Molenaar & Chiu, 2014; Moreno & Mayer, 2007; Pintrich, 2000; Zimmerman, 2003) used to solve problems (Lin et al., 1999). It helps the learner develop an understanding of oneself and related events in order to inform future actions (Sandars, 2009). Guided reflection and feedback could challenge learners while help them develop a deeper understanding of related content area (Sandars, 2009). The rich interactive features of multimedia-enhanced problem-solving instruction provides new means to support those reflection activities (Gordon, 1996; Liu et al., 2012). Relevant scaffolds are presented in Table 11, such as "What did you learn from this problem?", "Can you think of other setting where those skills could be applied?", and "What are the pros and cons of the chosen solution?" (Bulu & Pedersen, 2010; Ge & Land, 2004).

Media Attributes and Examples

Interactive features in eLearning authoring tools can be used effectively to design metacognitive scaffolds. The rich affordability of eLearning authoring tools allows designers, instructors, and other stakeholders to present a problem with utilizing a wide variety of media attributes, such as text, audio, video, simulation and animation. Text can be added by adding a textbox, audio can be made using audio recording or text-to-speech (Cannon, 2016). Videos can be created by uploading a pre-recorded video or linking to a

YouTube video. Highly interactive animation and games could also be created using the advanced features in eLearning authoring tools.

Interactive media types presented in this framework were identified from a variety of eLearning authoring tools, and examples were created using Adobe Captivate (see Figure 2 as an example). Those media types can be selected from the menu bar of eLearning authoring tools, which includes Text Box, Short Answer, True/False, Multiple Choice, Checkbox, Radio Button, Hyperlinks, Audio Input, and Animation (Articulate, 2016; "Captivate User Guide," n.d.). This framework aims to provide guidelines for instructors and designers to create metacognitive scaffolds in problem-based instruction. Instructional designers and instructors can choose from those suggested features to design appropriate metacognitive scaffolds. For instance, to create a question prompt, either a Multiple-Choice question or Short Answer can be used. However, instructors and designers can be creative in designing the instruction with altering the suggested instructional activities included in this framework or create new learning events using their preferred media features in eLearning authoring tools.

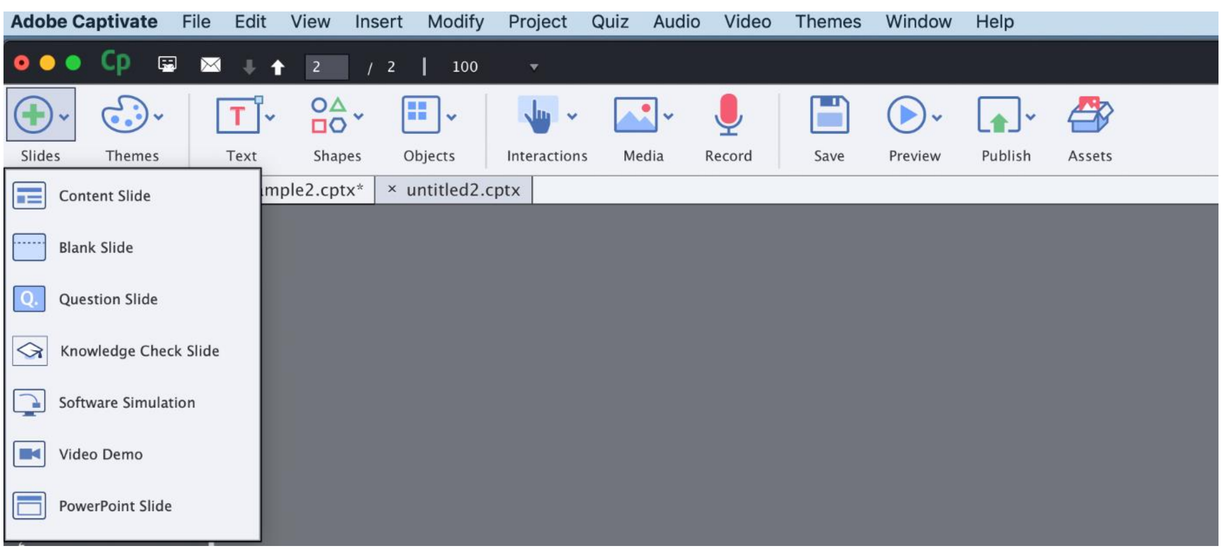

Figure 2. Adding Slides in Captivate

Ill-structured problem-based instruction can vary from simple courseware to animation and educational games with utilizing more advanced action in eLearning authoring tools. Because ill-structured problems have multiple solutions (Ge & Land, 2003, 2004; Jonassen, 1997, 2000), scaffolds included in this framework foster divergent thinking (Jonassen, 1997) by prompting learners to consider all aspects of the problem and all possible solutions. When the learner has difficulty in finding enough information for solving the problem, the learning materials will direct him or her to relevant resources. If learner does not make adequate progress, it will provide learner with cues and hints to proceed in the problems solving process.

Instruction produced using this framework offers personalized learning experiences by directing learners to different learning paths based on their interactions with the learning materials. This could be done using the branching function. Branching is a key feature that makes personalized learning experiences possible (Domazet & Gavrilović, 2015; Piecha, 2004; Weller, 1988), and it provides learner with pertinent feedback via answer validation (Piecha, 2004). Good feedback practices deliver high quality information, facilitate learners reflect on their learning processes, and improve learner performance, which in turn help learners develop self-regulation skills (Nicol & Macfarlane-Dick, 2006). Research shows that contextualized feedback could promote effective learning (Orsmond, Merry, & Reiling, 2005; Segedy, Kinnebrew, & Biswas, 2013). Feedback can be presented as suggestions for improvement, a probing question, or expert demonstration. Clarifying or exploratory questions, such as "can you explain…" could be asked to help learners monitor and evaluate their learning (Molloy & Boud, 2014).

The next section introduces various interactive media types in e-Learning authoring tools that can be used to create metacognitive scaffolds. Those media types include Multiple Choice questions, Short Answer questions, Text-to-speech, Drag and Drop activities, Notetaking, and Web Objects.

Multiple Choice Questions. Multiple Choice is a commonly used feature in eLearning authoring tools. It provides learner with pertinent feedback based on the selected answer(s). Figure 3 shows an example of monitoring scaffolds with using branching function to direct the learner to different learning paths, such as “Go to the previous slide”, “Go to the next slide”, or “Open URL or file”. Similar to Multiple Choice, True/False, Checkbox and Radio Button can be used to fulfill the same purpose with assigning variables in Advanced Action in Adobe Captivate (“Create learning interactions,” n.d.) and adding triggers and converting to freeform interaction in Storyline 360 (Fair, n.d.).

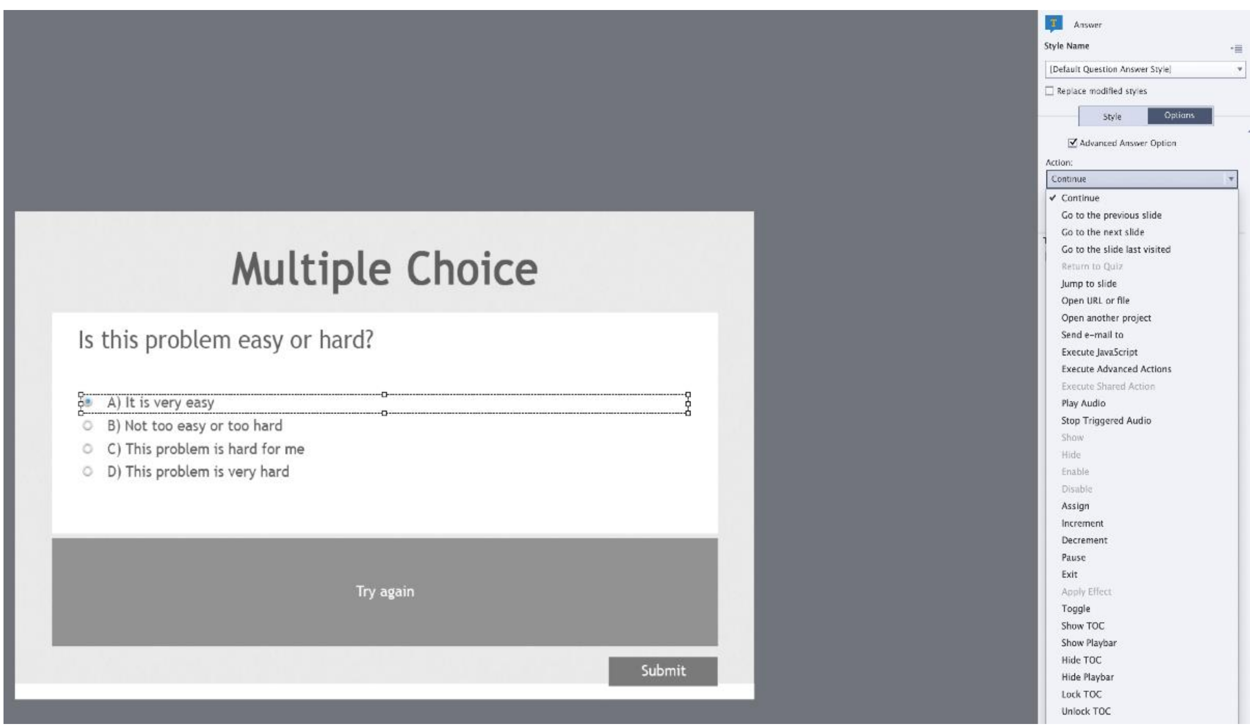

Figure 3. Adding Advanced Actions in Captivate

Short Answer Questions. Short Answer is regarded as an open-ended question, which prompts learner to respond to a question briefly with putting their thoughts into words (Pappas, 2015). A planning scaffold created using Short Answer Question and Button (e.g. Clear and Submit) in Captivate is shown in Figure 4, which asks the learner to present needed information and knowledge to solve a problem. Short Answer is also an ideal question format to train learner's argumentation and justification skills by asking learner to describe different solution paths and explain why they choose a solution.

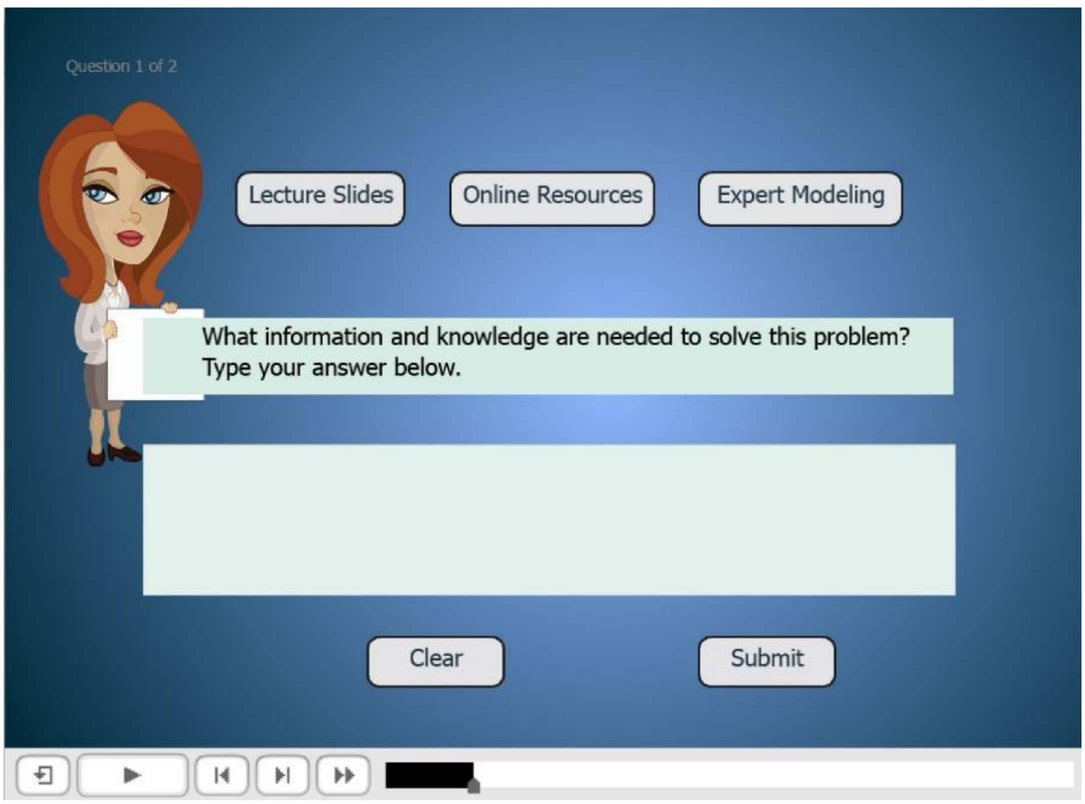

Figure 4. Sample image of metacognitive scaffolds in justifying solution stage

Text-to-speech. Text-to-speech allows the instructor and course designer to create audio from written texts or scripts (Fair, n.d.). Text-to-speech can be used to present a problem or elaborate on a topic in audio format in any stage of ill-structured problem-solving process. It helps e-Learning developers who are not native English speakers to produce audio narration. In addition, Text-to-speech is a great tool to design computer-based interactive content for visually impaired learners as well as learners who prefer audio instruction over plain texts.

Drag-and-drop Activities. Drag and drop function is widely acknowledged for creating engaging and immersive eLearning experiences (Pappas, 2015b). It allows learner to drag a target and drop it to a correct spot, which could be used to match, sort and label items. This feature can be used to create educational games where learner tries as many times as possible until they complete the task successfully. Figure 5 shows an orienting scaffold created using Drag and Drop feature in Captivate to differentiate causes and non-causes of air pollution.

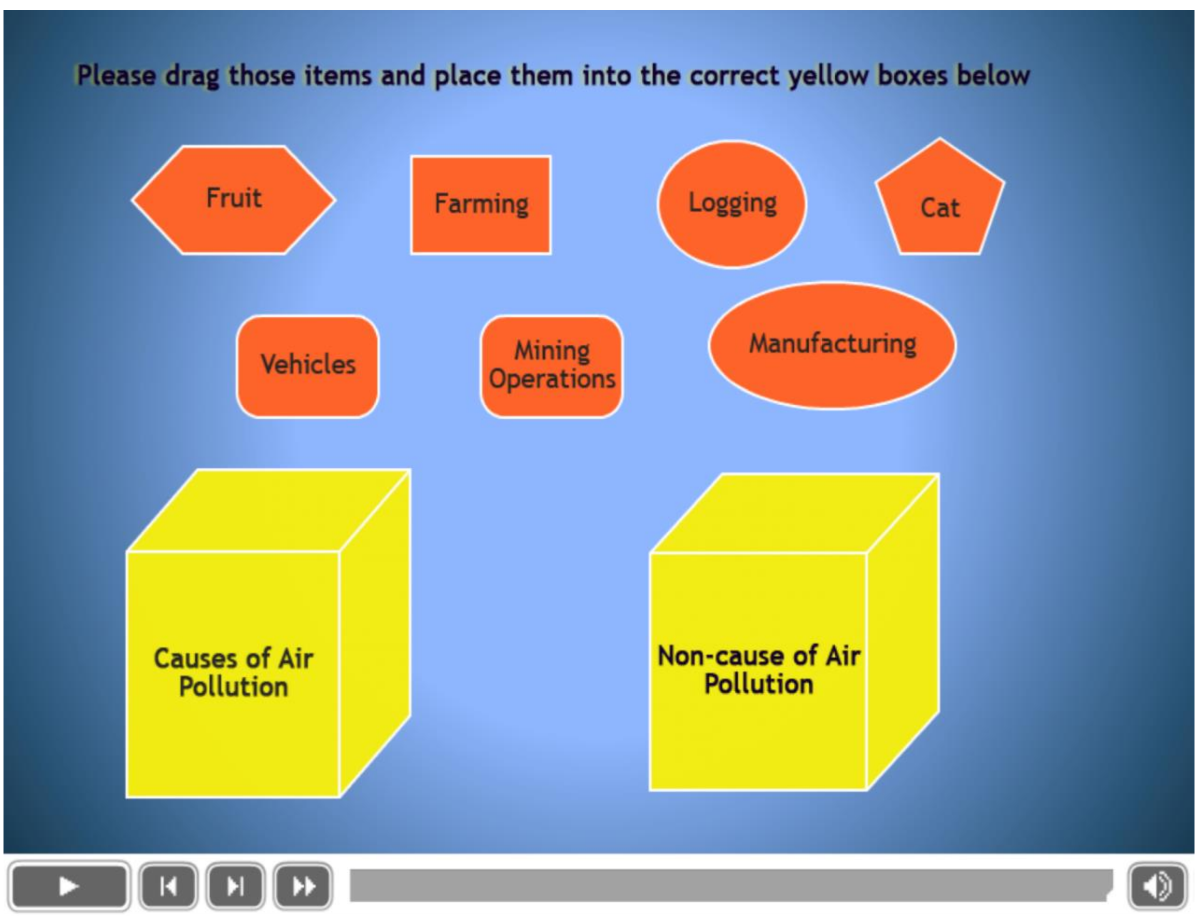

Figure 5. Problem orienting activity designed using drag and drop

Notetaking. Notes widget is used to create eLearning materials that allow learners to take notes during learning process ("Use the Learner Notes," 2018). Note-taking is an important learning strategy (Ackerman & Lauterman, 2012) that enhances knowledge retention (Özsoy, Memiş, & Temur, 2017). It is a process where learner organizes and comprehends information to create mental representation of new knowledge (Trevors, Duffy, & Azevedo, 2014). Trevors et al. (2014) found that metacognitive scaffolds could reduce shallow note-taking behaviors (e.g. reproducing learning content) of learners with low prior knowledge. This implies that implementing metacognitive scaffolds with note-taking features in eLearning content could potentially help learners with developing higher-level thinking skills while reducing rote learning behaviors.

Web Objects. Web objects including AI-based feedback systems, discussion forums, and chatbots can be added to e-Learning content. AI-based feedback system grade students' responses using machine learning methods and provides contextualized feedback immediately (Chen, 2004; Warschauer & Grimes, 2008). It supports metacognitive scaffolding with helping learners evaluate and reflect on their thinking processes. To promote reflective thinking, Discussion Forum could also be added to support peer interaction. Pedro, Abodeeb-Gentile and Courtney (2012) viewed Discussion Forum as an effective media to train metacognition. Peer feedback helps learners evaluate and revise their own responses (Ertmer et al., 2007; Van der Pol, Van den Berg, Admiraal, & Simons, 2008). In addition to integrating Discussion Forum in online materials, Chatbot could also be integrated to provide timely assistance to the learner. Chatbot is known as conversational agent (Kerry, Ellis, & Bull, 2008; Griol et al., 2014; Roda et al., 2001), or personal coach (Roda et al., 2001). It is an artificial intelligence application that implements natural language processing techniques to answer learners' questions (Clarizia, Colace, Lombardi, Pascale, & Santaniello, 2018; Kerry, Ellis, & Bull, 2008). Research showed that Chatbot helped learners develop self-regulation skills in problem-solving contexts (Beaumont, 2012).

Those web objects can be used effectively to create eLearning materials and provide contextualized feedback to learners. In discussion forum, learners received contextualized feedback from their peers and instructor. However, due to the asynchronous nature of communication in discussion forum, feedback may be given with delay. In comparison to instructor and peer feedback, AI-based technologies provide instant feedback and save the manual labor of grading (Chen, 2004; Warchauer & Grimes, 2008). It has been adopted in educational environments to give contextualized and continuous feedback to learners (Chen, 2004; Warschauer & Grimes, 2008). For instance, Wang, Chang and Li (2008) implemented automated grading of open-ended questions in science learning.

In alignment with Wang et al. (2008)'s idea to grade open-ended questions automatically. Open-ended questions in e-Learning materials could also be evaluated using AI techniques. AI techniques, such as Natural Language Processing, have been applied to develop automated writing evaluation (AWE) systems to assess students' essays (Dikli & Bleyle, 2014; Li, Link, & Hegelheimer, 2015). Automated feedback was found helpful to support learners with reflecting on and improving their writings. Several AWE systems also provide continued feedback for learners and allow iterative revisions of learner responses (Chen, 2004; Warschauer & Grimes, 2008). The implementation of AI-based Feedback System in e-Learning content could play an important role in supporting learners with developing metacognitive strategies, such as evaluating and reflecting.

In addition to Multiple Choice, Short Answer, Text-to-Speech, Drag and Drop, Notes, and Web Objects, other media types, such as Hyperlinks and Highlight Box (Jonassen, 2000), Matching (Pappas, 2015c), Hotspot (Brooks, n.d.) are also available across eLearning authoring tools. More complex ill-structured problem-solving learning materials and environments, such as Educational Games (Pappas, 2015b), can be created with utilizing and combing appropriate media types.

Table 8

Revised Design of Computer-based Metacognitive Scaffolds in Represent Problem Stage

Metacognitive strategies	Instructional strategies	Examples		Interactive media type
		Questions	Feedback	
	Understand problem (Belland, Glazewski, & Richardson, 2008; Kale et al., 2018)	Do you understand the problem?	IF learner answers "Yes", he/she will be prompted to explain the problem using his/her own words (Kim & Hannafin, 2011; King, 1991; Kramarski & Friedman, 2014). IF learner answers "No", he/she will be prompted to discuss the problem with the Chatbot or his/her peers in Discussion Forum.	True/False Checkbox Radio Button Audio Input Notes Hyperlink Web Objects (Chatbot; Discussion Forum)
Orient (Bannert & Reimann, 2012; Garofalo & Lester Jr,1985; Meijer, Veenman, & van Hout-Wolters, 2006; Molenaar & Chiu, 2014)	Examine causes of the problem (Jonassen, 1997; Kauffman, Ge, Xie, & Chen, 2008; Voss, 1988)	What are the causes of the problem? (Kauffman et al., 2008) Or The causes of the problem are___	Contextualized feedback will be provided by the instructor or AI-based Feedback System.	Short Answer Text Entry Box Fill-in-The-Blank Audio Input Notes Web Objects (AI-based Feedback System)
	Identify relevant and irrelevant information (Hollingworth & McLoughlin, 2001; Swanson, 1990)	What information is relevant to solve this problem and what information is irrelevant? (King, 1991)	Contextualized feedback will be provided by the instructor or AI-based Feedback System.	Drag and Drop Multiple Choice Short Answer Text Entry Box Radio Button Audio Input Notes Web Objects (AI-based Feedback System)

	Identify constraints, parts, variables, relations (Ge & Land, 2004; Kale et al., 2018; Voss, 1988)	What are the key variables of this problem and how are they related? (Meijer et al., 2006)	Contextualized feedback will be provided by the instructor or AI-based Feedback System.	Short Answer Text Entry Box Drag and Drop Radio Button Audio Input Notes Short Answer Web Objects (AI-based Feedback System)
Plan (Brown, 1987; Gordon, 1996; King, 1991; Kirsh, 2005; Molenaar & Chiu, 2014; Pintrich, 2002; Shin, Jonassen, & McGee, 2003; Zimmerman, 2003)	Identify missing information (Ge & Land, 2004)	What information is missing? (Ge & Land, 2004) Or Missing information includes___	Contextualized feedback will be provided by the instructor or AI-based feedback system.	Text Entry Box Notes Checkbox Radio Button Audio Input Fill-in-The-Blank Web Objects (AI-based Feedback System)
	Identify available resources/information (Bannert & Reimann, 2012)	What resources or information are available to solve the problem? Or Available resources/information to solve this problem include___	Contextualized feedback will be provided by the instructor or AI-based Feedback System.	Short Answer Text Entry Box Notes Checkbox Radio Button Audio Input Fill-in-The-Blank Web Objects (AI-based Feedback System)
	Activation of prior knowledge and experience	Do you have any related experience with this kind of	IF learner answers "Yes", he/she will be prompted to elaborate on his/her relevant experience to this problem.	True/False Text Entry Box Audio Input Notes

	(Huttenlock, 2007; Meijer et al., 2006; Shahbodin & Bakar, 2010; Yıldız-Feyzioğlu, Akpınar, & Tatar, 2013)	problem? (Shahbodin & Bakar, 2010)	IF learner answers “No”, he/she will be prompted to discuss the problem with the Chatbot or his/her peers in Discussion Forum.	Button Hyperlinks Interactive video Animation Simulation Web Objects (AI-based Feedback System)
	Goal Setting (Bannert & Reimann, 2012; Garofalo & Lester, 1985; Yıldız-Feyzioğlu et al., 2013)	What is/are your goal(s) and/or sub-goals for solving this problem? Or My goal(s) and/or sub-goals for solving this problem is/are ____	Contextualized feedback will be provided by the instructor or AI-based Feedback System.	Short Answer Text Entry Box Audio Input Notes Fill-in-The-Blank Web Objects (AI-based Feedback System)
	List needed knowledge/information (Shahbodin & Bakar, 2010)	What information and knowledge are needed to solve this problem? Or To solve this problem, ____ are needed	Contextualized feedback will be provided by the instructor or AI-based Feedback System.	Short Answer Text Entry Box Audio Input Notes Drag and Drop Checkbox Radio Button Fill-in-The Blank Web Objects (AI-based Feedback System)

Table 9

Revised Design of Computer-based Metacognitive Scaffolds in Generate Solutions Stage

Metacognitive strategies	Instructional strategies	Examples Questions	 Feedback	Interactive media type
	Propose solutions (Shahbodin & Bakar, 2010)	What are possible solutions for this problem? (Ge & Land, 2003; Shahbodin & Bakar, 2010) Or Solutions for this problem include ___	Contextualized feedback will be provided by the instructor or AI-based Feedback System.	Short Answer Text Entry Box Audio Input Notes Fill-in-The-Blank Web Objects (AI-based Feedback System)
Plan (Brown, 1987; Gordon, 1996; King, 1991; Kirsh, 2005; Molenaar & Chiu, 2014; Pintrich, 2002; Shin, Jonassen, & McGee, 2003; Zimmerman, 2003)	Formulate action plan (Huttenlock, 2007; Kapa, 2001; Meijer et al., 2006)	What are the steps to solve this problem? (Hollingworth & McLoughlin, 2001; Shahbodin & Bakar, 2010) Or Steps that it takes to solve this problem include___	Contextualized feedback will be provided by the instructor or AI-based Feedback System.	Short Answer Audio Input Text Entry Box Notes Fill-in-The-Blank Web Objects (AI-based Feedback System)
	Select strategy (Huttenlock, 2007)	Which strategy/strategies will you use? (Tzohar-Rozen & Kramarski, 2014) Or Strategy/Strategies that you will use to solve this problem include___	Contextualized feedback will be provided by the instructor or AI-based Feedback System.	Short Answer Audio Input Text Entry Box Notes Fill-in-The-Blank Web Objects (AI-based Feedback System)
	Identify needed information (Bulu & Pedersen, 2010;	What information do you need to solve this problem? (Bulu & Pedersen, 2010)		Short Answer Audio Input Text Entry Box Checkbox

	Huttenlock, 2007; Swanson, 1990)	Or To solve this problem, you will need_____ (Bulu & Pedersen, 2010)	Contextualized feedback will be provided by the instructor or AI-based Feedback System.	Radio Button Notes Fill-in-The-Blank Web Objects (AI-based Feedback System)
	Find information/data (Bannert & Reimann, 2012)	Where can you find the information? (Bannert & Reimann, 2012) Or You can find information from ___	Contextualized feedback will be provided by the instructor or AI-based Feedback System.	Short Answer Text Entry Box Audio Input Notes Fill-in-The-Blank Web Objects (AI-based Feedback System)
	Propose evaluation criteria (Swanson, 1990)	What are the necessary elements of an acceptable problem solution? (Belland, 2013) Or Components that need to be included in the problem solution are__	Contextualized feedback will be provided by the instructor or AI-based Feedback System.	Short Answer Text Entry Box Audio Input Notes Fill-in-The-Blank Web Objects (AI-based Feedback System)
Monitor (Brown, 1987; Efklides, 2014; Gordon, 1996; King, 1991; Kirsh, 2005; Pintrich, 2000; Zimmerman, 2003)	Data/Information generation (Huttenlock, 2007)	Do you find needed information to solve this problem?	IF learner answers "Yes", he/she will be prompted to answer the next question. IF learner answers "No", he/she will be given three options, including "Clicks into the Resources tab to study relevant materials", "Ask the Chabot", and "Seek help in the Discussion Forum".	True/False Checkbox Radio Button Audio Input Web Objects (Chatbot; Discussion Forum)

	Goal checking (Bannert & Reimann, 2012)	Are you reaching your goals? (Huttenlock, 2007)	IF learner answers “Yes”, message says “good job!” will appear on the screen. IF learner answers “No”, message says “Keep working. You will get there!” will appear on the screen.	True/False Checkbox Radio Button Audio Input
	Strategy implementation (Kwang, 2000)	Are you using the strategy that you chose? (Kwang, 2000)	IF learner answers “Yes”, he/she will be prompted to the next question. IF learner answers “No”, he/she will be prompted to discuss other strategies with the Chatbot or his/her peers in the Discussion Forum.	True/False Checkbox Radio Button Audio Input Short Answer Text Entry Box Web Objects (Chatbot; Discussion Forum)
	Check progress (Bulu & Pedersen, 2010; Ge & Land, 2003, 2004; King, 1991; Kwang, 2000)	Are you on the right track?	IF learner answers “Yes”, message says “Keep the good work!” will appear on the screen. IF learner answers “No, I am lost”, message says “Please review your plans, which may help you get back on track” will appear on the screen. IF learner answers “No, I am stuck”, he/she will be prompted to discuss this issue with the Chatbot or seek help in the Discussion Forum.	Multiple-Choice Checkbox Radio Button Audio Input Backward Button Web Objects (Chatbot; Discussion Forum)

Table 10

Revised Design of Computer-based Metacognitive Scaffolds in Present and Evaluate Solution Stages

Metacognitive strategies	**Instructional strategies**	**Examples**		**Interactive media type**
		Questions	**Feedback**	
	Justify proposed solution (Bulu & Pedersen, 2010; Ge & Land, 2003,2004; Kauffman et al., 2008; Meijer et al., 2006)	What are your reasons and/or arguments for proposing this solution? (Ge & Land, 2003) Or You selected this solution because of___ (Bulu & Pedersen, 2010)	Contextualized feedback will be provided by the instructor or AI-based Feedback System.	Short Answer Text Entry Box Notes Fill-in-The-Blank Web Objects (AI-based Feedback System)
Evaluate (Bannert & Reimann, 2012; Brown, 1987; Gordon, 1996; Meijer et al., 2006; Molenaar & Chiu, 2014; Schmidt & Ford, 2003; Yıldız-Feyzioğlu et al., 2013)	Assessment of supporting evidence/information (Bulu & Pedersen, 2010)	Is your evidence appropriate to convince someone of your solution?	IF learner answers "Yes", he/she will be prompted to explain why the evidence supports the proposed solution. IF learner answers "Not sure" or "Don't know", he/she will be prompted to return to the last section to re-plan, re-collect and re-evaluate the evidence and solution. IF learner chooses "Need Help", he/she will be prompted to discuss his/her question(s) with the Chatbot or peers in the Discussion Forum.	Multiple Choice Checkbox Radio Button Backward Button Notes Web Objects (Chatbot; Discussion Forum)
	Check with evaluation criteria (Swanson, 1990)	Did your solution meet the pre-set evaluation criteria?	IF learner answers "Yes", message says "Good job!" will appear on the screen.	Multiple Choice Checkbox Radio Button Audio Input

			IF learner answers “Not sure” or “Don’t know”, message says “Please review the evaluation criteria and refine your solution accordingly. You can also discuss your solution with the Chatbot or peers in the Discussion Forum” will appear on the screen.	Backward Button Web Objects (Chatbot; Discussion Forum)
	Consider perspectives from all stakeholders (Ge & Land, 2004)	Have you taken into account the perspectives of different stakeholders? (Ge & Land, 2004)	IF learner answers “Yes”, message says “Great!” will appear on the screen. IF learner answers “Not sure” or “No”, he/she will be prompted to consider perspectives of different stakeholders.	Multiple Choice Checkbox Radio Button Audio Input Backward Button
	Identify side effects (Ge & Land, 2004)	Did you point out the side effects and approaches to reduce them when presenting your solution?	IF learner answers “Yes”, message says “Fantastic!” IF learner answers “No” or “Not sure”, he or she will be prompted to refine the solution with analyzing side effects or discuss the side effects with the Chatbot or peers in the Discussion Forum.	Multiple Choice Checkbox Radio Button Audio Input Backward Button Web Objects (Chatbot; Discussion Forum)

Table 11

Revised Design of Computer-based Metacognitive Scaffolds in Reflect Stage

Metacognitive strategies	Instructional strategies	Examples: Questions	Examples: Feedback	Interactive media type
Reflect (Meijer et al., 2006; Molenaar & Chiu, 2014; Moreno & Mayer, 2007; Pintrich, 2000; Zimmerman, 2003)	Knowledge acquisition (Bannert & Reimann, 2012)	What did you learn from this problem?	Contextualized feedback will be provided by the instructor or AI-based feedback system. In the meantime, learner will also be prompted to discuss the answer the Chatbot or peers in the Discussion Forum.	Short Answer Text Entry Box Audio Input Notes Web Objects (AI-based Feedback System; Chatbot; Discussion Forum)
	Knowledge transfer (Lin, Newby, & Foster,1994; Liu, Horton, Toprac, & Yuen, 2012; Kirkley, 2003)	Can you think of other settings where those skills could be applied?	Contextualized feedback will be provided by the instructor or AI-based feedback system. In the meantime, learner will also be prompted to discuss the answer the Chatbot or peers in the Discussion Forum.	Short Answer Text Entry Box Audio Input Notes Web Objects (AI-based Feedback System; Chatbot; Discussion Forum)
	Present alternative solutions (Ge & Land, 2003, 2004)	What are other solutions? Why didn't you choose them?	Contextualized feedback will be provided by the instructor or AI-based feedback system. In the meantime, learner will also be prompted to discuss the answer the Chatbot or peers in the Discussion Forum.	Short Answer Text Entry Box Audio Input Notes Web Objects (AI-based Feedback System; Chatbot; Discussion Forum)
	Identify pros and cons of proposed solution (Ge & Land, 2004)	What are the pros and cons of the chosen solution? (Bulu & Pedersen, 2010; Ge & Land, 2004)	Contextualized feedback will be provided by the instructor or AI-based feedback system. In the meantime, learner will also be prompted to discuss the answer the Chatbot or peers in the Discussion Forum.	Short Answer Text Entry Box Audio Input Notes Web Objects (AI-based Feedback System; Chatbot; Discussion Forum)

Appendix B: IRB Approval Letter

VIRGINIA TECH.

Division of Scholarly Integrity and
Research Compliance
Institutional Review Board
North End Center, Suite 4120 (MC 0497)
300 Turner Street NW
Blacksburg, Virginia 24061
540/231-3732
irb@vt.edu
http://www.research.vt.edu/sirc/hrpp

MEMORANDUM

DATE: June 18, 2019

TO: Barbara B Lockee, Qing Zhang

FROM: Virginia Tech Institutional Review Board (FWA00000572, expires January 29, 2021)

PROTOCOL TITLE: Development of a Computer-based Interactive Content Design Framework to Facilitate Metacognition in Solving Ill-structured Problems

IRB NUMBER: **19-070**

Effective June 18, 2019, the Virginia Tech Human Research Protection Program (HRPP) and Institutional Review Board (IRB) determined that this protocol meets the criteria for exemption from IRB review under 45 CFR 46.104(d) category(ies) 3(i)(A),3(i)(B).

Ongoing IRB review and approval by this organization is not required. This determination applies only to the activities described in the IRB submission and does not apply should any changes be made. If changes are made and there are questions about whether these activities impact the exempt determination, please submit a new request to the IRB for a determination.

This exempt determination does not apply to any collaborating institution(s). The Virginia Tech HRPP and IRB cannot provide an exemption that overrides the jurisdiction of a local IRB or other institutional mechanism for determining exemptions.

All investigators (listed above) are required to comply with the researcher requirements outlined at:

https://secure.research.vt.edu/external/irb/responsibilities.htm

(Please review responsibilities before beginning your research.)

PROTOCOL INFORMATION:

Determined As:	**Exempt, under 45 CFR 46.104(d) category(ies) 3(i)(A),3(i)(B)**
Protocol Determination Date:	**June 18, 2019**

ASSOCIATED FUNDING:

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Appendix C: Expert Review Invitation Letter

Dear Dr. ________,

This is Qing Zhang. I am a PhD candidate in Instructional Design and Technology at Virginia Tech. I am currently working on my dissertation under the supervision of my PhD advisor Dr. Barbara Lockee. My dissertation focuses on the development of a framework to guide the design of interactive content using eLearning authoring tools to facilitate metacognitive development in solving ill-structured problems. It belongs to Type II Design and Development research – model research, which aims to guide instructional design process. Instructors and course designers could follow the guidelines provided in this framework to develop computer-based instruction to teach and train metacognition to solve ill-structured problems in various disciplines and settings.

Evaluation is critical to validate and improve this framework prior to its deployment. As a well-recognized expert in Instructional design, Metacognition and Problem solving, you are invited to review this framework. Your comments and feedback are extremely valuable and will be greatly appreciated! An expert review package that contains the link to an online evaluation survey and the framework itself will be delivered to you via email upon your agreement in this study. Your responses and feedback will be presented in the Findings chapter of my dissertation with either revealing your identify or not in accordance to your preference. However, your participation is voluntary, and you can withdraw at any time.
It will take approximately 2-3 hours to review the framework and complete the evaluation survey. Your expertise and feedback will be of great help for me to propose more valid and reliable guidelines for creating interactive content to teach and train metacognition. For any questions or concerns about participating in this study, feel free to contact me at qingz@vt.edu.

I hope you could accept this invitation! Thank you for your time and consideration. I look forward to hearing from you soon.

Yours sincerely,
Qing Zhang,
PhD Candidate, Instructional Design and Technology
Virginia Tech

Appendix D: Expert Review Package

Dear Dr. _____,

Thank you very much for agreeing to evaluate the framework that I have developed as an essential component of my dissertation that is chaired by Dr. Barbara Lockee at Virginia Tech.

The framework is utilized to guide the design of interactive content to facilitate metacognitive development in solving ill-structured problems, and it is attached within this email. The evaluation survey for this framework can be accessed via the following link: https://virginiatech.qualtrics.com/jfe/form/SV_07crNuseQe6rUFL
It will take approximately 2-3 hours to review the framework and complete the survey.

Please submit your survey responses prior to 11pm on July 25th. If you have any questions, feel free to contact me at qingz@vt.edu.

Thanks again for your participation!

Yours sincerely,
Qing Zhang
PhD Candidate, Instructional Design and Technology
Virginia Tech

Appendix E: Expert Review Survey

The purpose of this survey is to collect your feedback on developing a computer-based interactive content design framework to facilitate metacognition in solving ill-structured problems. This framework will be used as a guideline for instructional designers, instructors as well as other key stakeholders to create problem-based interactive content using eLearning authoring tools. Results of this study will be published in the researcher's dissertation. It is expected to take two to three hours to finish the entire research study, including one to two hours of reviewing the framework and less than one hour to complete this survey. The only risk is effort involved in the survey. Your participation is voluntary, and you may withdraw at any time.

If you have any questions or requests for information relating to this research study or your participation in it, or if you want to voice a complaint or concern about this research, or if you have a study related injury, you may contact the researchers identified above. If you have any questions about your rights as a research subject or complaints regarding this research study, or you are unable to reach the research staff, you may contact the VT IRB office at irb@vt.edu.

There is no monetary compensation for participating in this study. Please choose "Yes" if you consent to continue.

I agree to evaluate this framework.

- Yes
- No

Enter reviewer's name: ____

Do you prefer to keep your identity confidential?

- Yes
- No
- Either way

Ill-structured Problem-Solving Stages:

1.Are the problem-solving stages presented in this framework reasonable and appropriate?

- Yes
- No (Please explain why? What changes would you suggest in those stages?)

Problem Representation Stage:

2.Does the problem representation stage include necessary metacognitive strategies (as presented in column 1 of Table 3)?

- Yes
- No (Please explain)

3.Are the instructional strategies presented in the problem representation stage relevant (as presented in column 2 of Table 3)?

- Yes
- No (Please explain)

4.Are examples listed in the problem representation stage appropriate (as presented in column 3 of Table 3)?

- Yes
- No (Please explain)

5.Are the interactive types in eLearning authoring tools suggested in the problem representation stage applicable (as presented in column 4 of Table 3)?

- Yes
- No (Please explain)

6.Is the system feedback provided in the problem representation stage appropriate and applicable (as presented in column 5 of Table 3)?

- Yes
- No

7.What additional comments or suggestions do you have for designing metacognitive scaffolds in the problem representation stage?

Problem Solution Generation Stage:

8.Does the solution generation stage include necessary metacognitive strategies (as presented in column 1 of Table 4)?

- Yes
- No (Please explain)

9.Are the instructional strategies presented in solution generation stage relevant (as presented in column 2 of Table 4)?

- Yes
- No (Please explain)

10.Are examples listed in the solution generation stage appropriate (as presented in column 3 of Table 4)?

- Yes
- No (Please explain)

11.Are the interactive types in eLearning authoring tools suggested in the solution generation stage applicable (as presented in column 4 of Table 4)?

- Yes
- No (Please explain)

12.Is system feedback provided in the solution generation stage appropriate and applicable (as presented in column 5 of Table 4)?

- Yes
- No

13.What additional comments or suggestions do you have for designing metacognitive scaffolds in the problem generation stage?

Solution Presentation and Evaluation Stages:

14.Do the solution presentation and evaluation stages include necessary metacognitive strategies (as presented in column 1 of Table 5)?

- Yes
- No (Please explain)

15.Are the instructional strategies presented in the solution presentation and evaluation stages relevant (as presented in column 2 of Table 5)?

- Yes
- No (Please explain)

16.Are examples listed the solution presentation and evaluation stages appropriate (as presented in column 3 of Table 5)?

- Yes
- No (Please explain)

17.Are the interactive types in eLearning authoring tools suggested in the solution presentation and evaluation stages applicable (as presented in column 4 of Table 5)?

- Yes
- No (Please explain)

18.Is system feedback provided in the solution presentation and evaluation stages appropriate and applicable (as presented in column 5 of Table 5)?

- Yes
- No

19.What additional comments or suggestions do you have for designing metacognitive scaffolds in the solution presentation and evaluation stages?

20.Does the solution reflection stage include necessary metacognitive strategies (as presented in column 1 of Table 6)?

- Yes
- No (Please explain)

21.Are the instructional strategies presented in the solution reflection stage relevant (as presented in column 2 of Table 6)?

- Yes
- No (Please explain)

22.Are examples listed in the solution reflection stage appropriate (as presented in column 3 of Table 6)?

- Yes
- No (Please explain)

23.Are the interactive types in eLearning authoring tools suggested in the solution reflection stage applicable (as presented in column 4 of Table 6)?

- Yes
- No (Please explain)

24.Is system feedback provided in the solution reflection stage appropriate and applicable (as presented in column 5 of Table 6)?

- Yes
- No

25.What additional comments or suggestions do you have for designing metacognitive scaffolds in the solution reflection stage?

Overall Evaluation

26.This framework is clear and easy to understand.

- Strongly agree
- Agree
- Neutral
- Disagree
- Strongly disagree

Please explain why you make this choice

27.This framework is applicable to guide instructional designers, instructors, and other key stakeholders to design metacognitive scaffolds in ill-structured problem-solving instruction.

- Strongly agree
- Agree
- Neutral
- Disagree
- Strongly disagree

Please explain why you make this choice

28.This framework can be used to design problem-based instruction in a wide range of disciplines and settings.

- Strongly agree
- Agree
- Neutral
- Disagree
- Strongly disagree

Please explain why you make this choice

29.What are other comments or suggestions for improving this framework?