EXPLORING NOVICE DESIGNERS' REFLECTIVE THINKING

IN SOLVING DESIGN PROBLEMS

by

YI-CHUN HONG

(Under the Direction of Ikseon Choi)

ABSTRACT

Design tasks are omnipresent in our everyday lives. When solving design problems, designers engage in reflective conversations with the artifacts to be designed. Previous research shows that reflective thinking is one of the critical factors in solving design problems. Nevertheless, very few empirical studies were conducted to thoroughly inspect designers' reflection, and examine the influence of their reflection on their design performance.

This dissertation explores the role of novice designers' reflective thinking in solving design problems. Specifically, this study presents a review of literature and a conceptual model on the role of reflection in solving design problems. Following the conceptual model was the development of a new questionnaire, namely Reflective Thinking in Solving Design Problems (RTSDP). The RTSDP questionnaire is utilized to explore novice designers' reflective thinking and investigate the relationship between novice designers' reflective thinking and their design performance.

This dissertation is presented in the alternative format and consists of three journal-ready manuscripts. The first manuscript describes a three-dimensional model that is used to guide the understanding of designers' reflective thinking. The three dimensions are the timing of reflection, the objects of reflection, and the levels of reflection. In the second manuscript, a new questionnaire, was developed based on the three-dimensional model, is presented. A total of 260 participants were recruited for validating the RTSDP questionnaire. The reliability and validity analyses were performed to confirm the quality of the questionnaire. Furthermore, novice designers' reflection patterns were captured by using the RTSDP questionnaire. The third manuscript reports the result of the study that was conducted to explore novice designers' reflective thinking and their design performance. Forty-four students who were enrolled in the Introduction to Micro- and Nano-Biotechnology course participated in this study. At the conclusion of participants' design project, participants self-assessed their reflection patterns with the RTSDP questionnaire. Also, their performance scores in their group project on a biomedical device design were collected. The results identified certain patterns of novices' reflection that yielded better performance in solving design problems. The manuscript concludes with implications for instructional strategies that promote novices' reflective thinking, and enhance their problem-solving abilities in design tasks.

INDEX WORDS: Reflection, Reflective thinking, Problem solving, Design problems, Ill-structured problem solving, Instructional design, Engineering design, Engineering education

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DEDICATION

I dedicate this dissertation to my beloved family, Hua-Chin Hung, Hsiang-Lan Pan, Ming-Tsung Hung, Ming-Hung Kao, and Chia-Jung Hsu. Your love and encouragement drove me to take and overcome every challenge in this journey.

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CHAPTER 1

INTRODUCTION

Design tasks are ubiquitous in our everyday lives. The result of design tasks is the creation of artifacts that change the world (Gero, 1990). In our society, numerous products and systems that surround us fail to meet our needs and satisfaction. Thus, there is a constant demand for designers to perform design tasks and continue to improve the quality of our life. As Rowland (1993) argued, to solve design problems is to create innovations that will improve currently unsatisfactory situations through a series of inquiries. Some examples of design tasks found in our daily lives include residential area design, software design, water delivery system design, and online learning environment design. Additionally, many intangibles surrounding our lives are the results of design activities, such as health insurance systems, air traffic control systems, and political campaign strategies. Design is not an easy task as designers need to imagine *that-which-does-not-yet-exist* to make it appear in a concrete form as a new, purposeful addition to the real world (Nelson & Stolterman, 2003). In addition, a good design provides added value to the manufacturing and developing stages. Not only that, but the quality of design also has major impact on primary business outcomes: cost, time, and the quality and capability of the products (Boehm, 1973; Fleischer & Liker, 1992; Goel & Pirolli, 1992). All told, design is clearly an important activity for the advancement of human life, but being able to design is not a natural talent for everyone. Indeed, the nature of design problems makes it difficult for designers, especially novice designers, to solve them successfully.

Design problems are known for their ill-structuredness and complexity. Three primary features contribute to the difficulty of generating a competitive design. First, in most design projects, designers are not provided with sufficient and comprehensive information regarding the goal of the project, the initial condition of the to-be-designed artifacts or systems, and the transformation processes from the initial condition to the goal state (Reitman, 1965; Simon, 1973). In addition, little information is provided to guide designers' evaluation of artifacts. Therefore, while designing, designers cannot be certain whether or not their decisions are right or wrong (Simon, 1973). Moreover, the feedback from end users is limited or delayed (Goel & Pirolli, 1992). Thus, being able to tackle the uncertainty and ambiguity of a design task is an important indicator of a good design. The second critical factor that influences designers' abilities to solve design problems lies in their knowledge level. Design tasks require designers to possess knowledge from multiple domains and be able to organize and retrieve particular knowledge when needed (Simon, 1973). The third feature that makes design problems difficult to solve is their context-dependence. Designers need to take into account a variety of contextual factors while making design decisions such as the support from clients, available budget and time, and politics within an organization (Wedman & Tessmer, 1993). Furthermore, designers need to consider the broader impact of their design on their community including the social, cultural, economic, and environmental issues. Given the various aspects that designers need to consider during a design process, designers without adequate training are likely to be overwhelmed.

Helping novice designers develop their abilities in solving design problems is a challenging task. It is difficult to introduce a set of systematic procedures as the best design guidelines for a novice to follow. Designers' levels of expertise and the distinctive requirements of a design task are likely to lead designers to adopt different approaches when solving design problems. The adoption of divergent approaches can be affected by various factors such as designers' knowledge, skills, personal assumptions, previous training, prior experience, working environments, available resources, and interactions with stakeholders (Lawson, 1997; Rowland, 1993). No matter what design approach designers adopt to solve design problems, an integral component that enables designers to create a successful design is designers' reflective thinking (Moallem, 1998; Rowland 1993; Schön, 1983, 1987).

Because of the ill-defined, complex and context-dependent nature of design problems, designers need to possess not only sufficient knowledge and skills but also the ability to reflect on their actions and decisions (Rowland, 1993, p.80). It is argued that designers' reflective thinking enables them to control their design processes (Rowland, 1993), handle problems that they have never encountered previously (Schön, 1983), and increase the frequency of iterations (Adams, Turns, & Atman, 2003). Perceiving the importance of reflection, scholars have devoted themselves to investigating designers' reflective thinking with different foci. For example, Schön (1987) observed an architect's design process and discovered that the designer engaged in reflective conversations with the materials of the given design task. A few studies conducted in the context of engineering design and instructional design reveal that reflection is one of the major activities found in a design process (Greeno, Korpi, Jackson, & Michalchik, 1990; Lloyd & Scott, 1994). Moreover, numerous studies have been dedicated to advancing the field by proposing strategies to facilitate novice designers' reflection (e.g.,Bennett, 2010; McDonnell, Lloyd, & Valkenburg, 2004; Wetzstein & Hacker, 2004) and providing long-term courses designed for educating novice designers to become reflective designers (Shambaugh & Magliaro, 2001; Visscher-Voerman & Procee, 2007). In summary, much effort has been invested to understand designers' reflection and develop strategies that encourage novice designers' to exercise reflection.

Designers' reflective thinking has been deemed critical in a design process and thus has been widely investigated. Most of the previous studies have primarily emphasized discovering designers' reflective thinking only or identifying instructional strategies that promote designers' reflection. Very few empirical studies were conducted to examine the relationship between designers' reflection and their design performance. A group of scholars in the engineering field examined the design processes of freshman and senior engineering students (Adams, Turns & Atman, 2003). They discovered that senior students who transitioned more frequently between the problem definition and solution stages demonstrated higher frequencies of reflection. As a result, they yielded a higher level of performance. Another study also conducted in the context of engineering design shows that the design team that began to engage in reflection at the early stage of their design process performed better than the design team who only reflected frequently toward the conclusion of their design project (Valkenburg & Dorst, 1998). The findings of these two studies reveal the relationship between designers' timing of reflection and their design performance. As design problems are ill-structured and complex, designers can reflect on various issues in a design process. According to Visscher-Voerman and Procee (2007), "the concept of reflection is vague, meaning different things for different persons, and students have difficulty in doing it" (p. 344). Therefore, to effectively engage designers in reflecting upon assorted issues they may encounter in a design process, understanding these different issues and objects that designers may reflect upon becomes salient. In addition, for each time when designers reflect, the depth of their reflection may be different. In some situations, designers may reflect on whether or not they employ appropriate knowledge to make design decisions. In other situations, they may examine how they use their underlying assumptions to interpret the world. Thus, examining the depth of designers' reflection is deemed necessary to expand our understanding of designers' reflection. All in all, to advance this line of research, there is a need to conduct empirical studies to comprehensively investigate designers' reflection from multiple dimensions. Moreover, an exploration of designers' reflection and their design performance should be carried out so that educators and researchers will have the capacity to recognize novice designers' weakness in reflecting on and performing design tasks. Accordingly, educators and researchers will be able to develop an appropriate learning environment that not only facilitates designers' reflection but also improves their ability to solve design problems.

Dissertation Overview

The goal of the study is to understand the role of reflective thinking in solving design problems. The dissertation is presented in the alternative format of dissertation proposed by Duke and Beck (1999). It is a compilation of three published or ready to be published manuscripts:

- An article titled "Three Dimensions of Reflective Thinking in Solving Design Problems: A Conceptual Model"
- An article titled "Assessing Reflective Thinking in Solving Design Problems: The Development of A Questionnaire"
- An article title "Exploring Novice Designers' Patterns of Reflective Thinking and Their Design Performance"

The dissertation begins with an introduction (Chapter 1) which presents the need to examine designers' reflective thinking. In Chapter 2, the first article, *Three Dimensions of Reflective Thinking in Solving Design Problems: A Conceptual Model*, attempts to comprehensively capture different dimensions that encompass designers' reflective thinking. The paper begins with a discussion on the nature of design problems. Then, the paper presents the significance of reflective thinking in solving design problems as well as the definition of reflective thinking in the context of solving design problems. A series of inquires into the current literature led to the development of a three-dimensional conceptual model that examines designers' reflective thinking. These three dimensions are the timing of reflection, the objects of reflection, and the levels of reflection. Based on the three-dimensional model, some guidelines along with proposed instructional strategies are presented to demonstrate the use of the three-dimensional model to design a reflective learning environment for promoting reflection of novice designers in any design domain and also for improving their design ability. Additionally, to help instructional designers engage in reflection while performing instructional design tasks, a list of guided questions was developed based on the three-dimensional model.

The second paper (Chapter 3) is *Assessing Reflective Thinking in Solving Design Problems: The Development of A Questionnaire*. Based on the three-dimensional model proposed in the first article (Chapter 2), the Reflective thinking in Solving Design Problems (RTSDP) questionnaire is developed. The RTSDP is created for designers in any domains to self-assess their reflective thinking during the process of solving design problems. Following the development of the RTSDP questionnaire is a series of validation tests. The reliability and the validity of the questionnaire were examined using different statistical methods, including Pearson's correlation coefficients, Cronbach's alpha values, and exploratory factor analysis. In addition, novice designers' reflection patterns were captured using the RTSDP questionnaire. The different reflection patterns of novice designers in the fields of engineering and instructional technology were observed. The results demonstrate the need to consider novice designers' distinctive reflection profiles when identifying instructional strategies to facilitate their reflection. Last, the article concludes with research directions for using the RTSDP questionnaire in conducting further research in this line.

The third article (Chapter 4), *Exploring Novice Designers' Patterns of Reflective Thinking and Their Design Performance*, aims to investigate not only the reflection patterns of novice designers but also the influences of their reflection patterns on their design performance. The examination of designers' reflection is based on the three-dimensional model that was developed in the first article (Chapter 2). The tool for such investigation is the Reflective Thinking in Solving Design Problems questionnaire that is presented in the second article (Chapter 3). The investigation in the third article was guided by three main research questions. The first question explores the reflection patterns of novice designers using the three dimensions: the timing of reflection, the objects of reflection, and the levels of reflection. The second question examines the relationship between each aspect of novices' reflection and their design performance. The main goal of the second research question is to observe how various aspects of reflection lead to different levels of design performance. For the last research question, novice designers were categorized into two groups based on their design performance. A comparison of the reflection patterns of high performing novices and low performing novices was conducted. The results identified certain patterns of novices' reflection that yielded better performance in solving design problems. Implications for instructional strategies to promote novices' reflective thinking and enhance their problem-solving abilities in design tasks are discussed.

Finally, in Chapter 5, a summary of the key ideas from the three articles is presented. As studies exploring the role of designers' reflection in solving design problem are at the initial stage of understanding designers' reflective thinking comprehensively, many areas in this line of research are in need of further research efforts. To advance this line of research, the limitations of the current studies and the recommendations for future research directions are presented.

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CHAPTER 2

LITERATURE REVIEW

THREE DIMENSIONS OF REFLECTIVE THINKING IN SOLVING DESIGN PROBLEMS: A CONCEPTUAL MODEL

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Abstract

Design tasks are omnipresent in our everyday lives. Previous research shows that reflective thinking is one of the critical factors in solving design problems. Related research has attempted to capture designers' reflective thinking process. Yet a close inspection of designers' reflective thinking taking place during their design process demands further effort. To understand designer's reflective practice and to find better ways to promote novices' reflective thinking in solving real-world design problems, a comprehensive model was developed. This model identified three dimensions to guide the understanding of designers' reflective thinking during a design process: (1) the timing of reflection, indicating the points in the process where reflective thinking occurs, (2) the objects of reflection, showing the different types of objects that designers may reflect upon, and (3) the levels of reflection, referring to the different levels of designers' reflection. This model provides for meaningful aspects of reflective thinking to be situated in a design process, which can guide educators and instructional designers in developing appropriate learning environments for facilitating novice and practicing designers' reflective thinking. Moreover, the model can serve as a stepping stone for further research.

Introduction

In our daily lives, we not only encounter many design problems, but we also benefit from the outcomes of design problem solving. Some examples of design activities which are found in our everyday lives include architectural design, software design, engineering design, and instructional design. Additionally, many intangibles surrounding our lives are the results of design activities, such as educational systems, city traffic light control, and marketing strategies. The goal of solving design problems is to create innovations that will improve currently unsatisfactory situations through a series of inquiries (Rowland, 1993). Design is the foundation for manufacturing, constructing, and developing objects or systems (Fleischer & Liker, 1992; Goel & Pirolli, 1992). The ability to design is clearly a necessary element for the advancement of human life, yet it is not a talent that comes easily to everyone.

In the typology of problem solving proposed by Jonassen (2000; 2011), design problems are classified as a very ill-structured and complex type of problem because they lack an explicit definition of the problem, the goal of the problem, possible paths to reach the goal, and outcome evaluation criteria (Jonassen, 2000; Rietman, 1965; Simon, 1973). Problem solvers need to address the complexity and the ambiguity present in design problems because various elements such as constraints, desired functions, and perspectives from stakeholders are interrelated, yet these elements are unclear and may possibly conflict with each other (Jonassen, 1997; Simon, 1973). Changing the way these different elements are considered could lead problem solvers to new decisions and actions. Moreover, the context-specific nature of knowledge and skills and the necessity for integrating relevant knowledge and skills from multiple domains increase the difficulty of solving design problems (Goel & Pirolli, 1992; Jonassen, 2011; Rowland, 1993, Simon, 1973). Solving design problems in any fields can be challenging and laborious for designers, and can be even more difficult for novices who are learning to design. Therefore, guiding them in solving design problems becomes critically important.

Engaging novice designers in reflective practice is believed to be an important means of enhancing their competency in solving design problems (Heywood, 2005; Richey, Fields, & Foxon, 2001; Schön, 1983). Reflective designers are more likely to generate higher quality designs (Adams, Turns, & Atman, 2003; Rowland, 1993). Moreover, empirical studies have observed the importance of reflective activities in designer's design processes (Greeno, Korpi, Jackson, & Michalchik, 1990; Schön, 1987). Among novices, more reflection is found in the learners who are more experienced (Adams et al., 2003) and who perform better (Valkenburg & Dorst, 1998). Reflection enables designers to examine their thinking, their behaviors, design situations, and concerns from team members and stakeholders (Jonassen, 1997; Prudhomme, Boujut, & Brissaud, 2003; Schön, 1983, 1987).

Because of the ill-structured and complex nature of design problems, everyday designers reflect on a variety of issues during a design process. The complicated reflective thinking process of designers poses a challenge for researchers to investigate. Furthermore, the complicated nature of this process makes it difficult for educators and instructional designers to develop learning environments that could facilitate novice designers' reflective thinking for better performance in their design tasks in a certain domain. To guide educators and instructional designers in promoting learners' reflective thinking in solving design problems, we propose a conceptual model that aids understanding everyday designers' reflection patterns during their design processes. Ultimately, the model is intended to guide educators and instructional designers in designing a learning environment that could promotes reflection in novice designers while they perform design tasks in any domains. Moreover, the model is utilized to develop a list of prompting questions that support instructional designers' reflection in their instructional design practice. In the following sections, we will discuss the definitions of reflective thinking and the role of reflection in solving design problems. Then we will present the three-dimensional model for understanding designers' reflective thinking. Finally, this paper will conclude with implications for learning environment design, for instructional design practice, and for future research.

Reflective Thinking Defined

Reflection has been discussed in a number of disciplines. John Dewey first distinguished reflective thinking from other types of thinking, such as imagination, in 1933, defining reflective thinking as “active, persistent, and careful consideration of any belief or supposed form of knowledge in the light of the grounds that support it and the further conclusions to which it tends” (p. 9). He explained that the process of reflective thinking begins with one’s perplexity, which drives them to search for solutions to resolve the problem. Dewey (1933) further argued that to become a reflective practitioner, a person should be open-minded, whole-hearted, and responsible in his or her practice.

Following Dewey’s path, Schön (1983, 1987) agreed that reflective thinking is a significant factor in solving design problems. By interacting with problematic situations, people can research possible courses of action and derive new theories for particular situations based on previous experiences and already established theories. Thus reflection is regarded as an interactive conversation between the problem-solver and a problematic situation. Schön (1987) explained that the origins of one’s reflective thinking come from an element of surprise, such as unpleasant or pleasant moments, unexpected results, or unusual actions. This surprise usually conflicts with one’s existing tacit knowledge, which he called knowing-in-action. With such disequilibrium, some designers intentionally attend to the situation and exercise their reflection to address any emerging issue, while others choose to set the issue aside.

Another group of scholars, Boud, Keogh, and Walker (1985) described reflection as occurring when people recapture their experience, attend to their emotions related to the experience, mull it over, and evaluate it. A critical component that drives individuals in the reflective process is their intent. Although others can intervene with strategies to facilitate their reflection, whether or not and how much they reflect are their own decisions (Boud et al., 1985).

In addition to the use of reflection as a way to correct errors in their actions and decisions for accomplishing a task, reflection also provides an avenue for people to inspect the assumptions that they use to make meaning from the world (Mezirow, 1990, 1991). Mezirow highlights the importance of critical reflection because it is a means of directing individuals' awareness toward how their taken-for-granted beliefs and the personal values assimilating from their cultures influence their interpretations of the world. Issues such as social justice, equality, and emancipation are considered in regard to the decisions made for their practice. Through critical reflection, people may challenge the dominant beliefs and values of their society.

Aside from these Western perspectives, Confucius (500 BC), a philosopher from ancient China, regards reflection as examination of the inner self. His view of reflection particularly emphasized criticizing one's inner self with an aim to continually improving one's being and ethics. Confucius propagated the importance of transforming one's life into a meaningful existence by engaging in silent reflection on a daily basis (Wang & King, 2006). Silent reflection is an introspective contemplation that enables humans to appraise whether or not they treat others fairly, courteously, and morally (Zhu, 1992). It allows one to examine, understand, confirm, and verify the quality of one's existence in a society (Wang & King, 2006).

Based on these views of reflection, we define reflective thinking in the context of solving design problems as conscious mental activities that examine designers' courses of action, decisions, and their inner selves in given situations throughout a design process. With their introspective contemplation on various issues, designers actively derive new thinking and make changes to improve unsatisfactory situations. All of the designers' deliberate efforts to change their thinking, actions, and ways of interpreting the world, both on individual and societal levels, are considered to be acts of reflective thinking.

The Role of Reflection in Solving Design Problems

A number of researchers have highlighted the importance of reflective thinking in the process of solving design problems (Adams et al., 2003; Greeno et al., 1990; Rowland, Fixl, & Yung, 1992; Schön, 1983). Three reasons are identified below to illustrate the important role of reflective thinking in a design process.

Controlling Design Processes

An important aspect of designers' reflective thinking is that reflection allows designers to be conscious of their decisions in a design process. As Rowland (1993) argued, designers should possess the ability to reflect on each action they take so that they can generate the next appropriate move based on the situation and the feedback they have received as a result of previous actions. Similarly, Jonassen (1997) proposed that in order to successfully solve ill-structured problems, problem solvers should examine what they know in regard to the domain knowledge and then reflect on how they might arrive at a solution among all of the various alternatives. In their study of the design process, Lloyd and Scott (1994) observed that expert designers' reflection involves them in constantly monitoring, evaluating, and modifying their understanding of the problems and the generation of possible solutions. Greeno and his colleagues (1990) revealed that during an instructional design event, among instructional designers' behaviors, the second most frequent of their activities are their metacognitive activities. This is where instructional designers recapture, reflect, evaluate, monitor, and justify their actions as well as their decisions. With reflection, designers are able to control their design processes and derive appropriate strategies for their next move (Rowland, 1993).

Handling New Design Problems

Most design problems are context-dependent and domain-specific (Jonassen, 2000, 2011). The majority of new problems that designers face in real-world practice fall outside the range where they can solely apply professional knowledge learned from books and classes. Thus, many design problems are considered new to designers. Schön (1983) argued that it is unlikely that problem solvers can handle all possible situations in a new problem by rigidly following theories, techniques, or systematic procedures. Instead, he discovered that problem-solvers depend on "a kind of improvisation, inventing and testing in the strategies of [their] own devising" (Schön, 1983, p. 5). During the cycle of improvisation, inventing, and testing strategies, it is necessary for practitioners to bring reflection into play. Between two types of expertise that Hatano and Inagaki (1986) identified, adaptive experts closely attend to the effects of their actions on situations and derive appropriate strategies for their next moves, depending on the situation. Using reflection, adaptive experts can ensure equivalent satisfactory outcomes even when they face new circumstances. Likewise, when encountering new design problems, reflective designers are more likely to succeed when their reflection leads them beyond what they have previously experienced as they probe into uncertain or new conditions (Bransford & Nitsch, 1978). With their constant awareness of the situation, reflective designers will be more capable of devising a plan to solve novel problems.

Increasing the Frequency of Iterations

Reflective thinking helps designers to increase the frequency of iterations during a design process (Adams et al., 2003). Iterations in a design process are frequently observed in experts' behaviors (Atman et al., 2007). The process of iterations involves designers being actively engaged in reflection where they review the definition of a problem repeatedly so that they can reshape the appropriate problem space and carefully re-examine their proposed solutions (Adams, 2001). The frequent transitions between problem definition and solution generation coincide with Schön's (1983) idea of the situation's back-talk. Schön (1983) observed the process of an architectural design task, and he discovered a reflective conversation taking place between the designer and the ongoing situation. The designer paid close attention to the situation's back-talk when experiencing unexpected outcomes from previous moves. These unexpected instances direct the designer to appreciate the situation, reframe the problem, and generate alternatives accordingly until the proposed solution achieves a satisfactory outcome. It is the cycle of appreciations of the situations, actions, and re-appreciations that drives the iterative design process (Schön, 1987). Extending from Schön's belief in reflection, researchers in engineering design (Adams et al., 2003; Cross, 2004; Lloyd & Scott, 1994) and instructional design (Rowland, 1993; Shambaugh & Magliaro, 2001) echo Schön's position that reflection is the key element in achieving a high-quality design because it helps to increase the frequency of iterations between problem definition and solution generation.

In summary, scholars in the fields of design have advocated that reflection is a key aspect of improving one's design problem solving skills. With continual reflection, designers can function as a self-organizing system to control their design process; they will be able to think and execute more flexibly when dealing with new problematic situations; and they are more likely to achieve a high-quality design with their iterative design process.

A Three-Dimensional Model for Understanding Designers' Reflective Thinking

Designers' reflection plays an essential role in the process of solving design problems. To understand and utilize reflective thinking for solving design problems, a three-dimensional model is proposed to represent different aspects of designers' reflection. These three dimensions are the timing of reflection, the objects of reflection, and the levels of reflection as shown in Figure 2.1. The first dimension shows the timing when a designer engages in reflective thinking during a design process. Two design approaches—problem-driven and solution-driven—along with their corresponding design phases are identified to be explored when designers exercise their reflection. The second dimension demonstrates the objects upon which designers reflect. These objects are further categorized into three groups: reflection upon self, upon artifacts, and upon circumstances. The third dimension provides different levels of reflection—single-loop, double-loop, and triple-loop—to illustrate the perspectives upon which designers reflect.

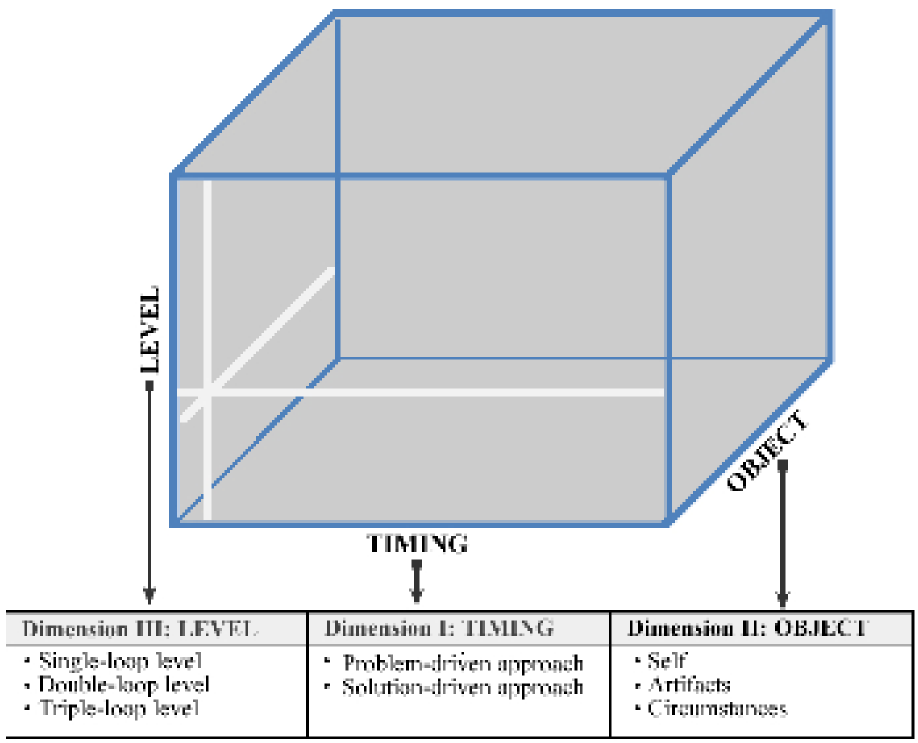

Figure 2.1. A framework for examining designers' reflective thinking during a design process.

Dimension I: Timing of Reflective Thinking

Reflective thinking can happen at any time and in any format. The function of Dimension I is illustrating the timing when designers are engaging in reflective thinking and exploring the associations between the timing of reflection and reflection patterns in a design process.

A good design is a result of several cycles of iterations during a design process (Adams et al., 2003). In a study conducted regarding the comparison of design processes between senior and freshman engineering students, more iterative behaviors were identified from the design processes of the seniors than from the freshman engineering students (Atman, Cardella, Turns, & Adams, 2005). The evidence of one's iterative design process lies in the transitions made between design steps. By being engaged in reflective thinking, designers will transition through different design steps, spend more time in iterative cycles, and increase the possibility of transitioning back and forth between problem definition and solution generation stages (Adams et al., 2003). Atman and her colleagues (2005) further concluded that the engineering students' iterative design behaviors positively correlate with their design success, which suggests that designers' reflection in a design process may influence their design performance and the quality of their products.

To understand the relationship between designers' reflective practice and their design process, the inquiry of the literature across different design disciplines, including instructional design (Gustafson & Branch, 2002; Visscher-Voerman & Gustafson, 2004), architectural design (Lawson, 1997), and engineering design (Atman et al., 2007; Cross, 2006; Heywood, 2005), has resulted in two generic design approaches: the problem-driven approach and the solution-driven approach (Cross, 1982; Lawson, 1997). In each approach, different design phases are recognized.

The Problem-Driven Approach

Designers using the problem-driven approach are depicted as resembling scientists (Cross, 1982; Lawson, 1997). The goal of their designs is to discover an optimized solution to a problem (Simon, 1981). Toward this end, designers using the problem-driven approach strive to gain a thorough understanding of the problem. Thus, they perform design tasks by defining and analyzing problems based on the collected data at the onset of the process. Their design process does not proceed to solution generation until they complete an extensive analysis of the situation (Cross, 1982). Both the solution generation and the evaluation of the proposed solutions are based on the already defined objectives, functions, and criteria. Numerous design models of the problem-driven approach are identified across different design disciplines, including instructional design (Dick, Carey, & Carey, 2009), architectural design (Krick, 1969; Maver, 1970), and engineering design (Eide, Jenison, Mashaw, & Northup, 2002). To capture the reflection patterns of designers applying the problem-driven approach, we have identified six essential phases that are shared across the models in Figure 2.2: (1) identifying a goal, (2) analyzing the problem, (3) defining the problem, (4) generating solutions, (5) evaluating solutions, and (6) making a decision. At the beginning of a design process, designers must first understand the problem in a broad, detail-free manner in order to set a general goal. Next, they begin to collect detailed information in order to analyze the situation. An in-depth exploration of the problem then leads designers to define the problem along with its functions, criteria, and constraints. On the basis of the problem definition, the designers move on to search for and generate all possible solutions that satisfy the already defined functions, criteria, and constraints. Subsequently, all of the solutions that have been generated are assessed against the defined specifications of the problem before the designers can reach a final decision.

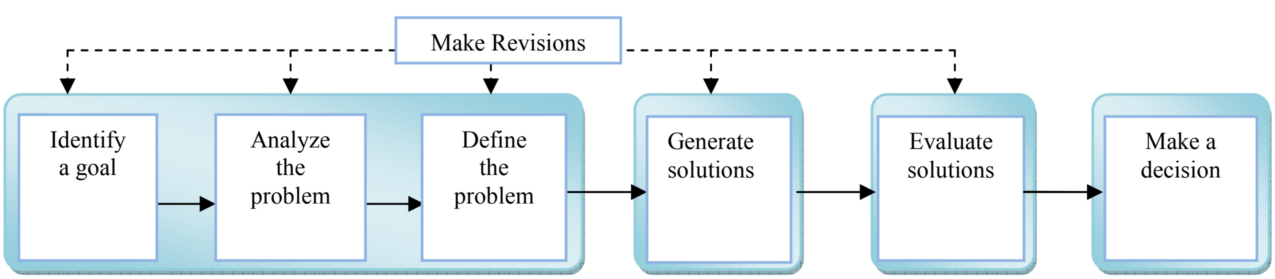

Figure 2.2. Dimension I: design phases for the problem-driven approach.

The Solution-Driven Approach

Unlike the problem-driven approach, the solution-driven approach is heuristic. The aim of the designers who are rooted in the solution-driven approach is to achieve a satisfactory solution, not an optimized one (Gregory & Design and Innovation Group at University of Aston in Birmingham, 1966; Jonassen, 2008; Simon, 1981). In some situations, design problems are not susceptible to an exhaustive analysis before any idea or solution is developed because an overarching design brief is often unavailable (Cross, 1982; Darke, 1979; Jonassen, 2008; Lawson, 1997). As a result, some scholars believe solving design problems with the solution-driven approach is the more feasible solution (Cross, 2000; Darke, 1979; Jeffery, 1991).

Designers espousing the solution-driven design approach conceive of the design process as an iterative cycle of decision making (Accreditation Board for Engineering and Technology, 2007; Cross, 2000; Hybs & Gero, 1992; Jonassen, 2008; Rowe, 1987). During a design process, designers need to make several decisions about the constraints, criteria, and functions of a design product. As Jonassen (2008) argued, the design process is a series of constraint explorations and constraint operations. The constraints are unveiled through the analyses of the possible solutions. In turn, solutions identified later are generated based on the emergence of the constraints. With the same concept, the objectives, criteria, and functions of a problem are usually established after the possible solutions are evaluated, analyzed, or criticized. Accordingly, the definition of the problem becomes clear. The solution generation and the definition of the problem co-evolve throughout the process (Kolodner & Wills, 1996; Ullman, Dietterich, & Stauffer, 1988). Similarly, Cross (2004) summarized that “the [design] problem cannot be fully understood in isolation from consideration of the solution” (p. 434). The solution-driven approach to the design process has less clear separation between the problem definition stage and the solution generation activities than the problem-driven approach does (Darke, 1979; Eastman, 1970; Hybs & Gero, 1992).

To illustrate the design process commonly observed in the solution-driven approach, four models from architectural design (Darke, 1979; Robinson, 1986), engineering design (Cross, 2000), and instructional design (Jonassen, 2008) have been identified. The design phases for the solution-driven approach presented in Figure 2.3 include the following: (1) identifying initial/more constraints, (2) generating a tentative solution, (3) analyzing the solution, (4) defining/redefining the problem, and (5) making a decision. The process begins with the recognition of a small number of constraints based on the designers' preconceptions. Next, the designers quickly fix on a possible solution based on their underdeveloped understanding of the problem. Then, a tentative solution is analyzed by taking into account the context of the situation. As a result, a definition of the problem will gradually be uncovered. In turn, this definition can also be used to explore further constraints or generate other possible solutions. The designers will end the design process when the identified solution reaches a satisfactory level.

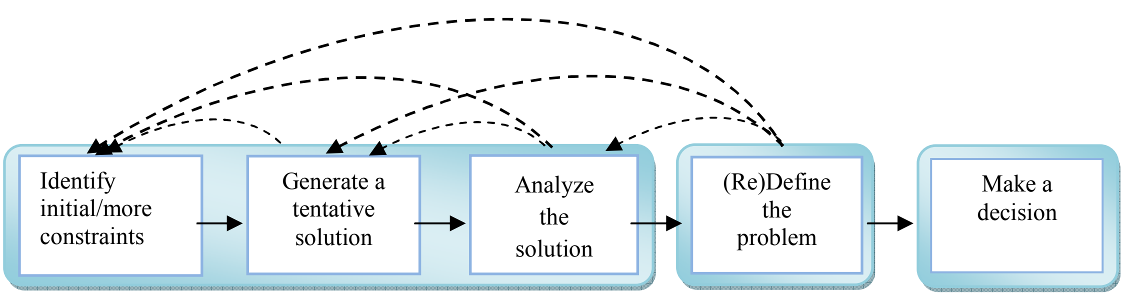

Figure 2.3. Dimension I: design phases for the solution-driven approach.

To conclude, the identification of the problem-driven and the solution-driven approaches has informed us that the problem-driven approach designers are likely to exercise more intensive reflection when defining the problem. On the other hand, the solution-driven approach designers tend to reflect more after solution ideas are generated and evaluated (Roozenburg & Cross, 1991).

Thus, having identified both design approaches along with their respective design phases, we are able to understand two different general patterns of designers' reflection. Moreover, the development of instructional strategies or learning environments for enhancing novices' reflection can be achieved by addressing the strengths and weaknesses of both types of design approaches.

Dimension II: Objects of Reflective Thinking

Since solving design problems is a large, complex, and ill-defined task, designers' reflective thinking can be complicated. Accordingly, the objects that designers reflect upon each time vary. As Visscher-Voerman and Procee (2007) assert, "the concept of reflection is vague, meaning different things for different persons, and students have difficulty in doing it" (p. 344). To make the reflective thinking situated in the context of performing design tasks more concrete, three different types of objects upon which designers reflect are identified: self, artifacts, and circumstances (See Figure 2.4).

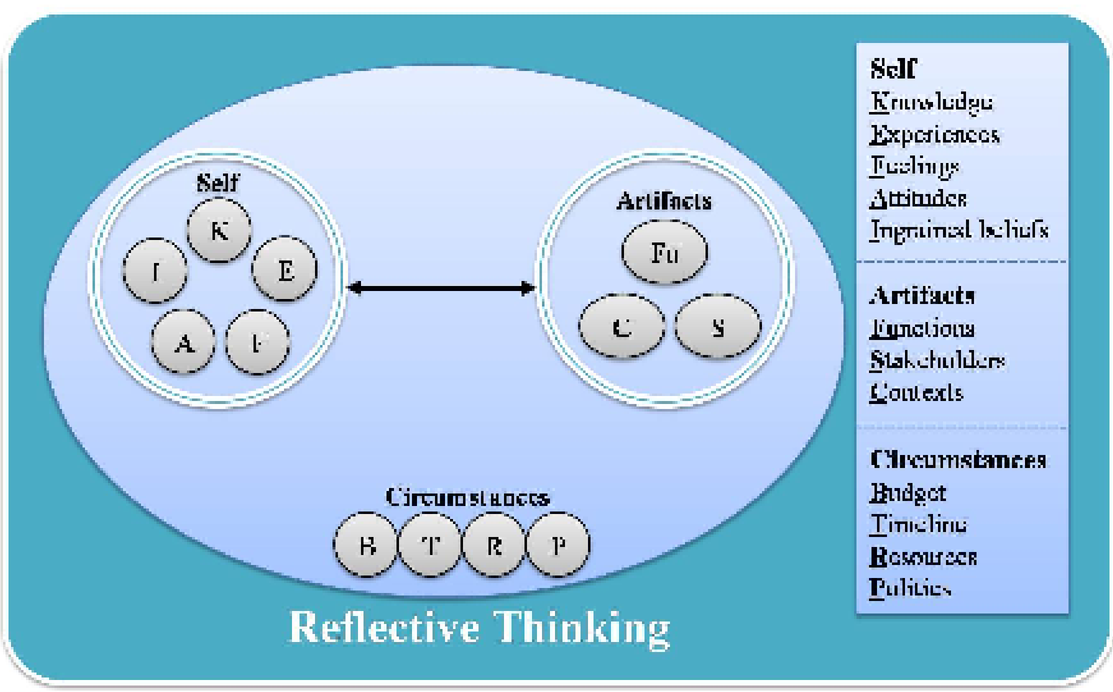

Figure 2.4. Dimension II: objects of reflective thinking.

Reflecting upon Self

Because the design process is a dialogue, the first and most obvious object that designers reflect upon is the self. As Cross explains (2000): “This dialogue occurs through the designer’s perception of the sketched concepts, reflection on the ideas that they represent, and their implications for the resolution of the problem” (p. 20). This dialogue enables designers to continuously examine their internal mental process when deriving solutions for a design task. Moreover, the idea of reflecting upon self is captured through self-reflection (Li, 1996; Lin & Schwartz, 2003), which directs designers to recognize their weaknesses in solving design problems and thus conquer challenges during a design process. Designers reflect on themselves about various objects, including their possessed knowledge, related experiences, feelings, attitudes, and ingrained beliefs.

Knowledge.

To succeed in solving design problems, possessing the knowledge relevant to the design tasks is instrumental for creating a high-quality design. Design tasks often require designers to integrate multiple knowledge domains (Simon, 1973); however, in practice, designers do not always equip themselves with all of the necessary knowledge. Furthermore, when an individual applies existing knowledge to solve the problem, the application of this knowledge may conflict with the problematic situation (Dewey, 1933). Such instances engage designers in reflective thinking, where they may discover knowledge that further improves their understanding of how to resolve conflicting situations. Therefore, it is central to the process that designers recognize their lack of knowledge or their inapplicable knowledge during a design process.

Related experiences.

In design practice, in order to generate potential solutions for the design problems they are currently facing, expert designers reflect back on their prior design experiences (Ahmed, Wallace, & Blessing, 2003; Marsh, 1997). Boud and his colleagues (1985) highlighted the importance of engaging individuals in reflecting on prior experiences. Visscher-Voerman and Procee (2007), who promoted reflection as a necessary component for educating instructional designers, have also maintained that providing novices with opportunities to reflect on issues related to their design experiences is essential. Visscher-Voerman and Procee's (2007) argument is based on Kant's (1781) conception of reflection: "concepts without experiences are empty, experiences without concepts are blind" (p. 345). By reflecting on any related experiences, designers can improve their understanding and their design ability.

Feelings.

During a problem-solving process, designers may experience moments of joyfulness, puzzlement, confusion, doubt, or mental difficulty (Dewey, 1933; Schön, 1983). By attending to their own feelings, designers continuously reflect on themselves in relation to the ongoing design process. As Schön (1983) argued, "when intuitive, spontaneous performance yields nothing more than the results expected for it, then we tend not to think about it. But when intuitive performance leads to surprises, pleasing and promising or unwanted, we may respond by reflecting-in-action" (p. 56). When experiencing mental discomfort, designers are triggered to examine the problematic situation and deal with it to overcome negative feelings. On the other hand, when experiencing moments of pleasure, designers bask in their success and are more willing to critically examine their performances for further improvement. With conscious effort to be truthful about their feelings, designers can bring about positive influences on their design ability (Boud et al., 1985).

Attitudes.

Capable designers should also examine their attitudes. Dewey (1933) asserted that "knowledge of the methods alone will not suffice; there must be the desire, the will to employ them" (p. 29). Dewey (1933) further urged practitioners to possess three attitudes: responsibility, whole-heartedness, and open-mindedness. With their responsibility and whole-heartedness, designers are more likely to overcome barriers during a design process, to be engrossed in a design task, and to take into account the consequences of their actions. An open-minded designer considers multiple perspectives, incorporates new ideas, and adopts alternative possibilities (Dewey, 1933). Having these three attitudes as Dewey (1933) described prevents designers from hasty and non-reflective design. Therefore, careful consideration should be given to examining designers' attitudes in order to ensure their persistence when they tackle problematic design tasks.

Ingrained beliefs and values.

Reflection enables designers not only to correct distortions in their understanding and errors in their problem solving, but also to critically examine the presuppositions upon which their beliefs have been built (Mezirow, 1990). This type of reflection is often labeled as critical reflection, which serves as a channel for designers to challenge their beliefs, their values, and the assumptions they have learned from their cultural backgrounds or social structures (Mezirow, 1991). When confronting challenges, through the use of critical reflection designers may become more empathetic, embracing divergent perspectives and taking into account situations where different groups of people are encountered. Designers engaging in critical reflection may bring about a new understanding of the problem as well as new ideas for solving problems.

Long before Mezirow's suggestion to foster critical reflection, Confucius (500 BC) also encouraged his followers to self-reflect. His idea of self-reflection is to deeply examine one's being in relation to the society to which one belongs. One of Confucius' followers, Tzeng Sen (500 BC), proposed a guideline in his *The Great Learning* for practicing self-reflection. One should reflect in three ways every day: In working for others, have I done the best I can? In my interactions with friends, have I been dishonest? In my learning, have I practiced what I have learned yet? Through daily introspective reflection, designers, like the general public, should intentionally examine the quality of their spirit, their ethics, their professionalism as individuals, and their contribution to their society (Wang & King, 2006). We believe such daily reflection would help designers create designs that demonstrate their professionalism as well as their social responsibility.

Reflecting upon Artifacts

In attempting to successfully solve design problems, it is insufficient for designers to merely reflect upon themselves. According to Maier and Fadel (2009), "in design, the entangled relationship between people and artifacts is inescapable, because artifacts are always designed for human use, usually designed by human themselves and situated within a larger context of a complex world economy" (p. 18). To tackle design problems, Maier and Fadel (2009) proposed the relational model of design to present the relationship between designers, users, and artifacts. The model shows the importance of engaging designers in reflecting upon the users as well as upon the products. Additionally, Schön (1987) demonstrated the interplay between designers and design situations. During a design process, designers "listen" to situations' "back-talk" that results from previous actions. With the need for designers to pay close attention to the products, the following section will focus on designers' reflection on product functions, on stakeholders' perspectives and perceptions, and on the context in which a product is operated.

Functions (Goals).

The primary goal of a design task is to create a product or a system that satisfies its functional requirements (Jonassen, 2008; Mostow, 1985). A series of the functions of an artifact or of the goals of a system is always the first aspect that designers examine: *What functions does this artifact need to perform? What does it need to do?* (Norman, 2004). The ultimate goal of a designer is to satisfy the needs of the stakeholders. To this end, a design process is a continual search of these needs. The search often starts at the very beginning of the design process when the designers frame the problem. However, it is unlikely that the designers can determine all of the essential functions or goals at one time. As Norman argued (2004), "people's needs are not as obvious as might be thought" (p. 70). It is through the iterative design processes that designers explore constraints and criteria and further identify the desired functions of or goals for a design task (Jonassen, 2008). Such attempts make the role of reflection essential. With designers' conscious effort in evaluating the interplay of people's needs, constraints, and criteria, a set of appropriate and desirable functions or goals are likely to emerge.

Stakeholders.

A good design can rarely be achieved without thinking about the stakeholders. The features of a design are influenced by the stakeholders' needs, their preferences, and the extent of their tolerance (Krick, 1969). The voice of the customers should always be recognized (Cross, 2000). However, in cases where commissioned customers and end users are different, good designers should also take into account the users' needs (Lawson, 1997; Newstetter & McCracken, 2001). Designers should avoid designing for themselves; instead, they should consider the users' perspectives (Newstetter & McCracken, 2001). To carefully examine user experience, a recommended approach for capturing users' perceptions, their perspectives, and the operations of an artifact is through observing users' experience with a product (Norman, 1996). This observation provides designers with opportunities to reflect on what they had perceived earlier and how they can modify their previous decisions and strategies now.

Contexts.

Intentional examination of the contexts in which a product is operated also contributes significantly to a good design. During a design process, designers evaluate the contextual factors that influence the operation of a product. Norman (1996) indicated that "in the actual [design] situation, cultural, social and organizational issues can dominate the user-oriented aspects of design" (p. 234). Moreover, a thorough inspection of the full economic and political effects of the use of a product on our society and on our environment is necessary (Asimow, 1962; Krick, 1969; Norman, 1988). As a change agent of human society, designers should reflect upon the impact of the contexts on the products. Likewise, designers also need to consider how products or systems reciprocally affect the environment. This should include reflection on how the products affect the environment both directly and indirectly as well as adversely and beneficially. Without examining these aspects, a desirable artifact is not likely to be developed.

Reflecting upon Circumstances

While many studies of designers' reflective thinking focus on how designers reflect upon themselves as well as upon artifacts (e.g., Dewey, 1933; Schön, 1983), little attention has been paid to the importance of guiding designers' attention to considering the circumstances surrounding design tasks (Kenny, Zhang, Schwier, & Campbell, 2005), which are frequently considered to be constraints for a given design task in real situations. These constraints include the budget, timelines, and the available resources for a project, as well as the politics within an organization. Jonassen (2008), using instructional design as an example, demonstrated that

Table 2.1
Types and Objects of Reflective Thinking

Type of Object	Object of Reflection				
Self	**Knowledge** (Dewey, 1933; Simon, 1973)	**Experiences** (Ahmed et al., 2003; Boud et al., 1985; Kant, 1781; Marsh, 1997; Visscher-Voerman & Procee, 2007)	**Feelings** (Boud et al., 1985; Dewey, 1933; Schön, 1983)	**Attitudes** (Dewey, 1933)	**Ingrained Beliefs and Values** (Confucius, 500 BC; Mezirow, 1990, 1991; Tzeng, 500 BC; Wang & King, 2006)
Artifacts	**Functions/Goals** (Jonassen, 2008; Mostow, 1985; Norman, 2004)	**Stakeholders** (Cross, 2000; Krick, 1969; Lawson, 1997; Newstetter & McCracken, 2001; Norman, 1996)	**Contexts** (Asimow, 1962; Krick, 1969; Norman, 1988, 1996)		
Circumstances	**Resources** (Jonassen, 2008)	**Budget** (Eide et al., 2002; Goel & Pirolli, 1992; Jonassen, 2008; Tessmer & Wedman, 1990)	**Time** (Eide et al., 2002; Goel & Pirolli, 1992; Tessmer & Wedman, 1990)		

designers usually take into account the following factors: available technologies, available funds and talents, and the rules or politics in organizational institutions. Additionally, a designer's performance can be affected by the allotted time as well as the budget (Eide et al., 2002, Tessmer & Wedman, 1990). In design practice, design activities are always entangled with project management issues. Kenny and his colleagues (2005) concluded that in practice, project management (e.g., creating a budget and tracking progress) actually consumes a significant amount of designers' time. This signifies the designers' endeavor to reflect upon these circumstances that interplay with their design processes. In addition to considering the aforementioned aspects, designers also need to examine how these factors affect the development or production stage (Fynes & Burca, 2005). A good design minimizes the cost and the time used during the development stage (Goel & Pirolli, 1992). All in all, designers' reflection upon circumstances should receive appropriate attention because the circumstances of a design task dominate not only the design process but also determine the quality of the final artifacts.

To summarize the existing literature on the different types of objects that designers may reflect upon during a design process, we have created Table 2.1, which includes the types, the objects in each type, and the corresponding literature.

Dimension III: Levels of Reflective Thinking

The other indispensable aspect for understanding designers' reflection is an examination of the level of designers' reflective thinking. In the proposed framework, each level of reflection is judged important, since each level assumes a different role in the process of solving design problems. For this dimension, Argyris and Schön's (1978) idea of single-loop learning and double-loop learning, as well as Flood and Romm's (1996) triple-loop learning, are considered in investigating the levels of designers' reflective thinking.

Single-Loop Reflective Thinking

During a design process, designers are likely to detect errors in their knowledge, their understanding of the end users' needs, the information they possess about available resources, etc. When errors are detected, designers reflect on what is going wrong. With single-loop reflective thinking, designers look for strategies or solutions to achieve a pre-defined goal. The single-loop level adopts means-end thinking (Flood & Romm, 1996). It enables designers to examine and explore alternative actions or solutions based on the criteria of efficiency and effectiveness to correct the errors and proceed toward the goal (Argyris & Schön, 1978; Usher &

Bryant, 1989). For example, when dealing with problematic situations, designers who are engaged in single-loop reflection ask themselves: *What other strategies, knowledge, or information can help me solve this design problem more efficiently and effectively? What other actions should I take to deal with this puzzling situation to achieve the already identified goal?*

Double-Loop Reflective Thinking

Designers' single-loop reflection is critical for their design performance. Nevertheless, to merely reflect at this level may not sufficiently resolve all problematic situations. Argyris and Schön (1978) took a further step and claimed the importance of reflecting upon the designers' already identified goals, functions, criteria, and constraints. This examination leads designers to question their assumptions in relation to their understanding of the problem (Mason, 2008). With double-loop reflective thinking, designers may ask themselves: *Is it legitimate to set such a goal and use these criteria to define this design problem? Does my problem definition appropriately address the problem?* In other words, designers who reflect at the double-loop level place less emphasis on the process or the strategies necessary to achieve the specified goal. Rather, they question their assumptions and understanding of a problem, which may lead them to re-identify the goal for a problem (Flood & Romm, 1996; Van Manen, 1977). Thus, reflection on the double-loop level may result in a series of cascading changes in a design process.

Triple-Loop Reflective Thinking

Designers who reflect at the triple-loop level consider moral or ethical issues, or they may take into account fairness or social justice in order to make decisions while carrying out a design task. Triple-loop reflection is similar to the idea of critical reflection (Mezirow, 1990; Moallem, 1998; Van Manen, 1977). Designers who reflect at this level examine the assumptions and presuppositions they use to make meaning out of their experiences (Mezirow, 1990).

Additionally, they challenge their perspectives that are shaped or constrained by the process of socialization or by the dominant culture. Such examination can influence how designers approach the design problem (Moallem, 1998). Some examples of triple-loop reflective thinking are: *When I design, do I attend only to the dominant culture? How are some ethnic cultures influenced by my design?* Triple-loop reflective thinking drives designers to reach beyond themselves and their own culture. By doing so, their design may possibly arrive at a large-scale transformation of their entire society. However, this level of reflection occurs much less often than single-loop and double-loop reflective thinking.

Conclusions

This paper has discussed the critical role of reflection in solving design problems and has provided a three-dimensional model which guides an understanding of designers' reflective thinking when solving design problems. This conceptual model is further used to propose strategies and guidance that will benefit educators and instructional designers in two directions. First, we provide strategies to design learning environments that facilitate novices' reflective thinking when performing design tasks in any domain. Secondly, we develop guidelines for instructional designers themselves to use to enhance their reflection while carrying out instructional design tasks. To conclude this paper, we propose three potential research directions that will help us advance the knowledge needed to promote designers' reflection and to improve their design performance.

Implications for Designing Reflective Learning Environments for Novice Designers

One of the major implications of the three-dimensional model is that this model can guide educators and instructional designers in creating better learning environments that will promotes novices' reflection while learning solving design problems. Based on the model, we are able to develop a list of several different foci of reflection. Next, we have identified possible examples of their corresponding instructional strategies (See Appendix 2.A). The list of instructional strategies classified according to our model, shown in Appendix 2.A, is a starting point to demonstrate how this framework can be used by educators and instructional designers for identifying, organizing, and integrating existing instructional strategies into coherent learning environments that will promote novices' reflection while solving design problems. The design of learning environments that consist of different strategies should take into account learners' needs and teaching contexts. Thus, considering the characteristics and levels of students, instructional designers can use the three-dimensional model and the suggested strategies as guidance in developing reflective learning environments. In the following section, we demonstrate how this model can be used to identify strategies for designing learning environments.

Reflective Learning Environment Design for Dimension I

When performing design tasks, everyday designers may adopt the problem-driven or the solution-driven approach. The problem-driven approach designers may exert more effort toward problem analysis and definition at the expense of generating more ideas, while the solution-driven approach designers may pay more attention to solution generation at the cost of appropriate problem analysis (Roozenburg & Cross, 1991). Using distinctive strategies may stimulate their reflection on the parts of the process to which they pay less attention. For novices who are learning or practicing the problem-driven approach for performing class design projects, providing a variety of case studies engages them in reflecting upon alternative choices and helps them to realize that changing their understanding of the problem at any stage may lead them to a better result (Bennett, 2010). Moreover, with the case studies, novices can be exposed to multiple perspectives which may possibly bring about more ideas (Bennett, 2010; Ertmer & Quinn, 2007).

On the other hand, strategies like displaying processes and providing prompts may particularly benefit novices who learn or practice the solution-driven approach in their given design problems because the unveiled design processes allow them to consciously monitor their analysis of the problems (Lin, Hmelo, Kinzer, & Secules, 1999). Furthermore, the prompts may direct novices to examine some critical aspects that they may overlook when they interpret the problem (Davis & Linn, 2000).

Reflective Learning Environment Design for Dimension II

Assorted strategies are identified to stimulate novices' reflection on different objects (i.e., self, artifacts, and circumstances), including providing cases, using prompt questions, involving learners in peer feedback sessions, asking learners to construct videos that describe their design processes, observing end users' operation of similar products or systems, and using off-the-shelf project management tools (See Appendix 2.A). Taking novices who do not consider stakeholders' perspectives and do not attend to the situational constraints of the context as an example, asking novices to observe end users' operation of similar products or systems may be an effective strategy. Norman (1996) argued that even end users themselves could not articulate their own needs. Therefore, through observation, novices may gain in-depth insights from end users and different stakeholders, explore contextual constraints, and begin to reflect on these two aspects.

Another example is to demonstrate guiding novices to reflect on the circumstances of the given design projects. A critical skill that practicing designers should possess is the ability to deal with project management issues (e.g., resource and time management) as it is observed as one of the most frequent activities during the practitioners' design processes (Kenny et al., 2005). Using cases along with project management tools engages novices' reflection in this aspect for two reasons. First, through cases, learners will realize that a variety of management issues need to be considered even before they begin a design project (Bennett, 2010; Ertmer & Quinn, 2007). Secondly, using management tools specifically directs novices to examine their allocations of resources, budget, and time. Such deliberate reflection may lead them to revise their decisions during a design process.

Reflective Learning Environment Design for Dimension III

The third dimension informs educators and instructional designers about ways to develop learning environments that will guide learners to reflect at all three levels of reflective thinking. From our preliminary study that explores novices' reflection patterns in the instructional design context, we learned that novices reflected the most frequently at the single-loop level and the least often at the triple-loop level (Hong & Choi, 2010). Different strategies should be applied to promote novices' reflection at the double-loop and triple-loop levels. For encouraging the double-loop reflection, providing an environment that allows novices to verbalize their understanding of the problem and of design decisions to another peer may direct their conscious awareness to examine their assumptions and their interpretation of the problem (Wetzstein & Hacker, 2004). The triple-loop level of reflection can be facilitated by engaging novices in conversations with people from different social groups (e.g., cultural, religious, or professional groups). Such an opportunity will provide them with a venue that challenges their underlying assumptions about broader issues such as social, cultural, historical aspects (Lin et al., 1999; Visscher-Voerman & Procee, 2007). Overall, more strategies calculated to promote novices' reflection on their design tasks can be identified by contemplating the three-dimensional model and the initial examples of instructional strategies we suggested in Appendix 2.A.

Implications for Instructional Designers Training and Practice

There is no doubt that this three-dimensional model can be applied to enhancing instructional designers' practice as well as to training prospective instructional designers by directing them to reflect while learning and performing instructional design tasks. A previous study that investigated the instructional design process reveals that the second most frequent behaviors observed in the design process are reflective and metacognitive activities (Greeno et al., 1990). During a design process, instructional designers may reflect on varied aspects and objects for appropriate decisions. Likewise, prospective instructional designers should be guided to reflect on the important aspects of design processes and products. Based on the three-dimensional model, for example, we have developed a list of guiding questions that will prompt different aspects of reflection during instructional design processes (See Appendix 2.B). These prompting questions can be used for both training and practicing instructional design, as we have successfully implemented the questions during a graduate course in instructional design (Hong & Choi, 2010). Practicing or prospective instructional designers may examine their reflective practices by using the proposed guiding questions on a regular basis. However, if time and situational constraints exist, depending on their needs and styles, instructional designers may use the list selectively to facilitate their instructional design processes. For example, most practicing and novice instructional designers reflect only at the single-loop level. To promote their reflection while also achieving the double-loop and triple-loop levels, practicing and novice instructional designers can be prompted to ask themselves the following questions during their design practice: *Does my current understanding of the design task appropriately address the problem? When I make decisions during my design process, do I consider only the dominant culture*? With these kinds of questions, practicing and novice instructional designers are guided to re-visit their understandings of the given design tasks and to examine their viewpoints of the value of the instructional products that they have developed.

Implications for Future Research

In this section, we suggest and discuss three future research directions that will help advance our knowledge for developing reflection capacity and improving design ability. To promote novices' reflection while solving design problems in different domains, the first step for researchers is to understand everyday designers' reflection patterns. From the existing studies, designers' reflection behaviors have been observed while performing engineering design tasks (Adams et al., 2003) and instructional design tasks (Greeno et al., 1990). To identify strategies that could facilitate novices' reflection, further research is needed to closely examine designers' reflection patterns (i.e., timing, objects, and levels of reflection). In Rowland's (1992) study, different approaches to performing the instructional design tasks have been observed from the design processes of both novice and expert designers. For example, novice designers interpreted the given instructional design task as well-defined by the given information, while expert designers regarded the task as ill-defined and questioned the given information. Moreover, Kenny and his colleagues (2005) found that practicing instructional designers invest a large amount of time in dealing with project management issues. However, in most projects given to students in class settings, project management issues are less emphasized. Because of the different levels of design expertise and the distinctive circumstances of the design tasks, we assume that expert designers may have different reflection patterns than the novice designers. To prepare novices for performing real-life design tasks, exploring the reflective patterns of expert designers will inform the design of learning environments that could promote novices' critical reflection behaviors and improve their design ability.

Another potential area for future research could focus on the assessment of reflection in solving design problems. It is important to assess designers' reflective thinking to be able to identify appropriate strategies for creating positive reflective learning environments and to be able to certify that learners have developed the capacity to design through reflection. However, reflection is intangible and barely observable, which makes it difficult to assess designers' reflection capacity (Visscher-Voerman & Procee, 2007). A few empirical studies have been conducted to understand designers' reflection, including Schön's (1983) case study in the context of architectural design and Adams and her colleagues' (2003) investigation of engineering students' reflection in lab-like settings by using the verbal protocol analysis method. The findings of these studies are conducive to our knowledge of designers' reflection. However, some limitations still exist. The results from a case study with one participant may not sufficiently represent a larger group of designers' reflection, while the research in a lab setting may miss some critical aspects of reflection which take place when performing real-life design tasks. Alternative methods of assessing designers' reflection capacity in a natural setting with a larger group of participants are needed. Two potential measurement tools for studying reflection are referenced from accounting education and health care education (Kember et al., 1999; Kember et al., 2000; Lucas & Tan, 2006). The first method required participants to document their reflection in journals. The journals later were evaluated by the reviewers based on coding schemes. Another method is to develop a questionnaire for designers to self-assess the reflection that occurred during their design processes. To investigate designers' reflection capacity, more effort is needed both for further development of the coding scheme and the questionnaire in the context of design problems, and for exploring other potential tools that will allow researchers to capture designers' reflection patterns.

The third area that demands further research is investigating the relationships between design performance and particular reflection profiles, and using the results to design and validate instructional strategies and learning environments which will facilitate reflection and improve design problem solving ability. In Appendix 2.A, a range of strategies are suggested to foster learners' reflective thinking based on the three-dimensional model. As we mentioned earlier, not all proposed strategies will be appropriate for all types of learners and assigned design tasks. Since designing learning environments for promoting learners' reflection itself is a design task, many questions remain to be explored. For example, among the proposed strategies, when is it appropriate to provide different support or strategies to learners? Additionally, the number of tasks assigned to learners may possibly influence their reflection and the quality of the final design performance. So, how do instructional designers achieve the balance between providing enough support or tasks to learners and engaging them in necessary reflection behaviors? What strategies are effective to support learners who have never performed design tasks and also those who have some design experience? These design considerations and questions can be informed by conducting more empirical studies that investigate the effectiveness of learning environments. For the journey of designing effective learning environments and validating the combinations of identified strategies, we recommend the design-based research approach in order to achieve both theoretical and practical goals (Reeves, 2000; van den Akker, Gravemeijer, McKenney, & Nieveen, 2006; Wang & Hannafin, 2005). Based on Wang & Hannafin's (2005) discussion, the characteristics of the design-based research methodology confirm its appropriateness for application in designing and investigating effective instructional strategies. Designing a good learning environment will undergo several iterations because there are interrelated issues and situational constraints to be explored. Meanwhile, researchers and practitioners both need to work closely with participants in real-world settings to assure the practicality of the design. To ensure the feasibility of proposed learning environments, the adoption of a variety of research methods and tools will increase the validity and generalizability of the findings.

To summarize, the three-dimensional model developed in this paper recognizes the difficulties inherent in facilitating novices' reflective thinking, and it endeavors to move forward our conceptualizations of reflective thinking taking place in the process of solving design problems. With our model, we are attempting to provide important aspects of reflective thinking that are related to the design process and performance. As the model opens up an opportunity to understand the role of reflective thinking in solving design problems, it also provides instructional designers and educators with basic guidance in designing learning environments that will promote designers' reflection in any design domain. In closing, we hope that this model stimulates further discussion on the nature of reflective thinking in solving design problems. Ultimately these efforts will improve designers' ability to solve the pervasive design problems facing our society.

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Appendix 2.A

Strategies for Designing Reflective Learning Environments

Dimension	Aspect	Focus of Reflection	Example of Instructional Strategy
Timing	Problem-driven Approach	• Identify a goal • Analyze the problem • Define the problem • Generate solutions • Evaluate solutions • Make a decision	• Provide various cases (Bennett, 2010) • Ask learners construct the video of their design processes in a narrative format (McDonnell et al., 2004)
	Solution-driven Approach	• Identify initial/more constraints • Generate tentative solutions • Analyze the solution • (Re)Define the problem • Make a decision	• Display learners' design process (Lin et al., 1999) • Use prompts to check learners' understanding (Davis & Linn, 2000) • Ask learners to construct videos of their design processes in a narrative format (McDonnell et al., 2004)
Object	Self • Knowledge • Experiences • Feelings • Attitudes • Ingrained Beliefs and Values	• Examine the lack of knowledge and the inappropriate application of acquired knowledge to the situation • Think back to previous experiences to understand the problem or generate solutions • Using the mental discomfort or the joyfulness from successful experiences to examine the design task • Examine if one possesses responsibility, open-mindedness, and whole-heartedness when dealing with a design task • Challenge the long-held beliefs, values, and assumptions learned from one's own cultural background or social structure	• Provide various cases (Bennett, 2010; Rowland et al., 1992) • Use prompts which focus on learners' knowledge, emotions, and personal beliefs and values (Davis & Linn, 2000; Lin & Lehman, 1999; Luppicini, 2003) • Involve learners in peer feedback sessions (Visscher-Voerman & Procee, 2007) • Ask learners construct videos of their design processes in a narrative format (McDonnell et al., 2004)

	Artifacts • Functions/Goals • Stakeholders • Contexts	• Observe users' needs • Identify constraints and criteria • Attend to multiple stakeholders' needs and requests; • Uncover users' needs, preferences, and the extent of their tolerance • Evaluate how the contextual factors (e.g., social, cultural, political) affect the decision making in the design tasks	• Provide various cases (Bennett, 2010; Rowland et al., 1992) • Ask learners to observe end-users operation of similar products or systems (Norman, 1996)
	Circumstances	• Attend to available time, available budget, available resources, etc.	• Provide various cases (Bennett, 2010) • Use management tools (e.g., Microsoft Excel®, Comindwork®)
Level	Single-Loop	• Look for strategies or solutions to achieve a pre-defined goal • Explore alternatives based on the criteria of efficiency and effectiveness to correct errors	• Display the learners' design process (Lin et al., 1999) • Use prompts (e.g., What is the most effective path to reach the goal?) (Lin et al., 1999)
	Double-loop	• Question underlying assumptions about a design task and the designer's understanding of the problem	• Ask learners to verbalize the design process (Wetzstein & Hacker, 2004) • Use prompts (e.g., How does your understanding of the problem improve the current situation?) (Lin et al., 1999)
	Triple-loop	• Consider moral or ethical issues • Take into account fairness or social justice to make decisions when carrying out a design task • Examine the assumptions and presuppositions for making meaning out of one's life experience	• Engage learners in conversation with people from different social groups (e.g., cultural groups, religious groups, or professional groups) (Lin et al., 1999; Visscher-Voerm & Procee, 2007) • Use prompts (e.g., When I design, do I only attend to the dominant culture?) (Lin et al., 1999)

Appendix 2.B.

Guidelines for Engaging Instructional Designers in Reflection

Dim I: Timing of Reflection	
Design Approach	**Examples of Guided Questions**
Problem-driven	• Have I come up with a number of ideas/solutions? • Have I overlooked any critical factors when I initially identified the goal?
Solution-driven	• What are critical factors that lead me to identify the problem? • Have I thoroughly understood the problem?
Dim II: Objects of Reflection	
	Examples of Guided Questions
Self Knowledge/Skills	• Am I familiar with the different instructional models? • Do I have sufficient knowledge to guide me in selecting the appropriate tools for the target audience(s)?
Self Experiences	• What was my experience as a learner/teacher/trainer? • What was my previous experience in similar instructional design projects?
Self Feelings	• How do I feel--excited, frustrated, or confused? And where do these feelings come from?
Self Attitudes	• Am I using all of my capacity to create a high-quality instructional design product for the end users? • Am I open-minded enough to listen to others' suggestions? • Am I responsible enough for the target audience(s) and other stakeholders?
Self Ingrained belief and values	• What are my personal values and how do they contribute to the decisions I made during the design process? • Do I consider the needs of those learners from different cultural, ethnical, social, and economic groups?
Artifact Functions/Goals	• What is the goal of the learning module? • What ability will learners possess after learning from the product?
Artifact Stakeholders	• What goal does the client desire to reach? • What are the needs and preferences of the target audiences? • Are there other stakeholders' perspectives that I need to take into account?
Artifact Contexts	• Does my design fit the learning context? • What is the learners' performance context?
Circumstances Time	• Do I plan appropriate time for each design task? • Am I keeping up with the schedule?
Circumstances Resource/ Budget	• What equipments are available? • Which personnel are available for the project? • Have I appropriately allocated budget resources?
Dim III: Levels of Reflection	
	Examples of Guided Questions
Single	• What are strategies which might help me efficiently achieve my goal? • What other actions should I take to achieve the already identified goal?
Double	• Does my current understanding of the design task appropriately address the problem?
Triple	• Is it legitimate to set such a goal and use these criteria to define the current problematic situation? • When I make decisions during my design process, do I consider only the dominant culture? • How may some ethnic cultures be influenced by my design?

CHAPTER 3

ASSESSING REFLECTIVE THINKING IN SOLVING DESIGN PROBLEMS: THE DEVELOPMENT OF A QUESTIONNAIRE

[1] Hong, Y.C. and I. Choi. To be submitted to *British Journal of Educational Technology.*

Abstract

Previous research argues that reflection is a critical factor in successfully solving ill-structured design problems. Existing studies have identified various instructional strategies to facilitate novice designers' reflection. Two methods were widely adopted to investigate the effectiveness of the strategies. One method is to explore the change of designers' reflection by using the case study method. The other method is to use the improvement of design performance as evidence to demonstrate the effectiveness of the strategies. In addition to these methods, we propose that using a questionnaire can be another effective tool. In this study, we aim to develop a new questionnaire, namely Reflective Thinking in Solving Design Problems (RTSDP) for designers to self-assess their reflection in three dimensions: the timing, the objects, and the levels of reflection. This questionnaire is developed based on a three-dimensional model for reflective thinking (Hong & Choi, in press). A total of 260 participants were recruited to participate in the pilot and formal tests. The reliability and validity analyses were performed to confirm the quality of the questionnaire. Furthermore, participating designers' reflection patterns were captured by using the RTSDP survey. The different reflection patterns of participants in the fields of engineering and instructional technology were observed. The results will further guide the design of the instructional strategies that facilitate novice designers' reflection.

Introduction

The ability to solve design problems is widely demanded in our society. Design is called for when the existing products or systems fail to satisfy the current needs (Gero, 1990). The goal of design is to transform the desired functions into a concrete form or a description (Nelson & Stolterman, 2003; Gero, 1990). In the process of transformation, designers deal with the uncertaintity and complexity of design. Explicit information, such as problem definitions, project goals, paths to reach the goal, and outcome evaluation criteria, is rarely provided (Jonassen, 2000; Reitman, 1965; Simon, 1973). Additionally, designers are required to consider and evaluate numerous components, interrelated or contradictory, to make appropriate decisions (Jonassen, 2008; Simon, 1973). Moreover, designers should possess knowledge and skills from multiple domains and be able to apply them in contextually appropriate situations (Goel & Pirolli, 1992; Jonassen, 2011; Rowland, 1993, Simon, 1973). These characteristics of design tasks pose challenges for designers, and especially for novices.

To develop designers' ability in solving design problems, reflective thinking has been identified as one of the critical factors that has an influence on one's design process (Adams, Turns, & Atman, 2003; Schön, 1983; Greeno, Korpi, Jackson, & Michalchik, 1990). Reflective thinking allows designers to control and monitor their design processes (Lloyd & Scott, 1994; Rowland, 1993), enables them to handle new design problems (Schön, 1983), and increases the frequency of iterations during a design process, which is often regarded as an indicator of a high quality design (Adams, Turns, & Atman, 2003). Perceiving the importance of reflection, educators and researchers in the field of design have developed a variety of strategies that promote designers' reflection. For example, providing cases to novice designers increases their collection of vicarious experiences that they can use as references for future design tasks (Bennett, 2010; Rowland, Fixl, Yung, 1992). Posing a series of questions for novice designers is another strategy that stimulates their reflective thinking while performing design tasks (Luppicini, 2003, Wetzstein & Hacker, 2004). Asking students to record and construct a video describing their design processes purposely directs them to reflect back on their design experience (McDonnell, Lloyd, & Valkenburg, 2004). Moreover, Visscher-Voerman and Procee (2007) developed and implemented a semester-long course that primarily teaches systematic reflection to novice educational designers.

To confirm the effectiveness of the above strategies, two approaches were widely adopted. One approach is to conduct the qualitative research by using the case study method to demonstrate designers' reflection as a result of the proposed strategies (e.g., McDonnell et al., 2004). Another approach is to conduct the experimental research that determines the effectiveness of the proposed strategies by providing designers' growth of design capacity as evidence (e.g., Wetzstein & Hacker, 2004). While these two approaches have provided insights into ways of investigating the strategies that promote designers' reflection, using a questionnaire can be another method that elicits meaningful data to verify the proposed strategies. According to Luppicini (2003), reflective thinking is implicit and difficult to operationalize. The concept of reflection is vague, meaning different things for different people (Visscher-Voerman & Process, 2007). Due to the abstract concept of reflective thinking and the complex nature of design problems, the examination of designers' reflection can be a challenging task for researchers. However, we believe that the well-designed questionnaire could be an efficient tool to systematically inquire into designers' reflection patterns during a design process and help advance the research related to designers' reflection in two directions. First, the questionnaire can be utilized in a comparison study to see whether or not there was a change in designers' reflection resulting from the strategies (Kember et al., 2000). Second, the questionnaire can also enable educators and researchers to probe into novice designers' reflection patterns when performing a design task without any intervention. Such investigation will further inform educators and researchers to develop reflective learning environments that are suitable for the novice designers with specific reflection capacity and divergent levels of design expertise in many different domains. Thus, the primary goal of the study is to develop a questionnaire, namely Reflective Thinking in Solving Design Problems (RTSDP) for investigating designers' reflection patterns. This paper first describes the theoretical foundations that guide the development of the questionnaire. Then, the process of developing and validating the questionnaire is reported. Third, the reflection patterns of the participating students are analyzed to demonstrate how the questionnaire can be utilized. The paper is concluded by discussing the implications of utilizing the RTSDP questionnaire for future research.

Three-Dimensional Framework to Evaluate Designers' Reflection

The development of the questionnaire is guided by the three-dimensional model (Hong & Choi, in press). Based on the model, designers' reflection is examined from three dimensions: the timing of reflection, the objects of reflection, and the levels of reflection (See Figure 3.1).

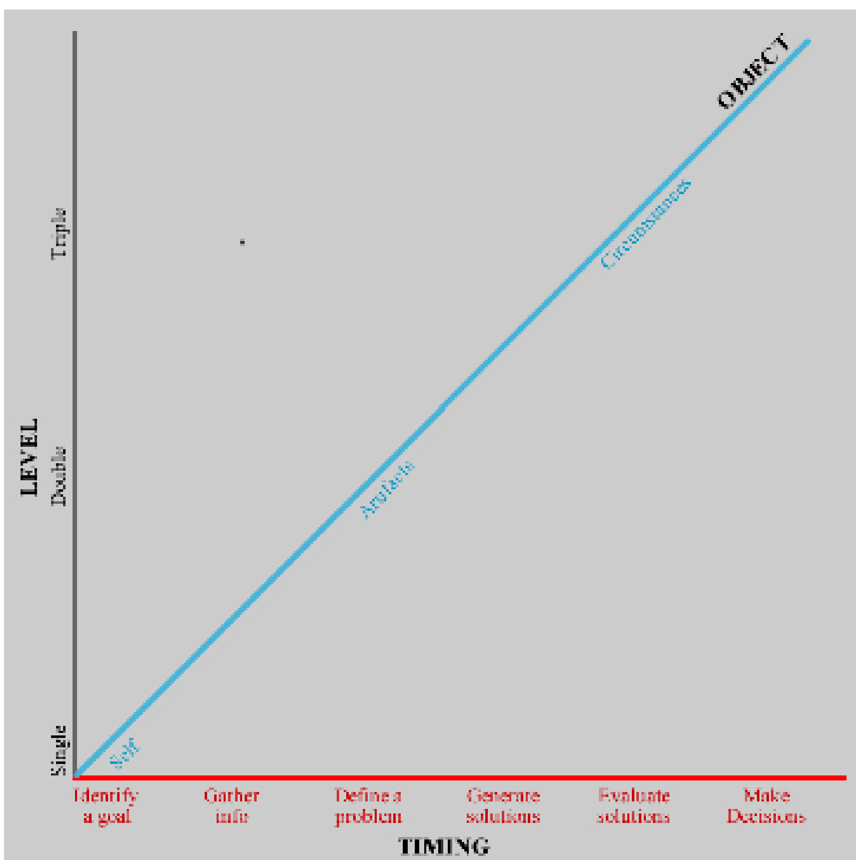

Figure 3.1. A framework for capturing designers' reflective thinking.

Dimension I: Timing of Reflection

Designers' reflection occurs at any time and in any format. Dimension I intends to examine the timing when designers are thinking reflectively. A good design is the result of several cycles of iterations during a design process (Adams et al., 2003). In a study conducted to understand the design processes of senior and freshman engineering students, more iterative behaviors were found from the design processes of seniors than from freshman engineering students (Atman, Cardella, Turns, & Adams, 2005). Senior students frequently shifted among different design stages throughout the entire design process, while freshman students spent large chunks of time in each design stage. Moreover, senior students moved among more different design stages than freshman students. The transitions were the results of their reflection (Adams et al., 2003). Another study shows that the engineering design team, beginning to reflect at an early stage and continuing to reflect throughout their design processes, performed better than the design team that reflected frequently only toward the end of the design process (Valkenburg & Dorst, 1998). These studies have shown that the timing of reflection may influence the quality of the final design. Therefore, the examination of when designers exercise their reflection helps us understand designers' reflection patterns. To explore when designers engage in reflection, two methods are identified. One is to examine the design period in which designers exercise reflection and another way is to inspect the design stages in which reflection occurs.

Dimension II: Objects of Reflection

Solving design problems is a large, complex, and ill-structured activity (Jonassen, 2000; Simon, 1973). The objects that designers reflect upon each time vary, and the intangible nature of reflection makes it difficult to capture. As Maier and Fadel (2009) argued, "in design …

artifacts are always designed for human use, usually designed by human themselves and situated within a larger context of a complex world economy" (p.18). With the features of design tasks, we identified three categories of objects that designers may reflect upon: reflection on self, the artifacts being designed, and the circumstances of the design tasks (See Table 3.1).

Reflecting upon Self

The design process is a dialogue between designers and design tasks (Schön, 1987). In this process, designers demonstrate their unique abilities by constructing the sketched concepts about the design task, using reflection to examine their emerging thoughts and actions, and proposing a resolution to the problem (Cross, 2000, Maier & Fadel, 2009). To create a design that satisfies stakeholders' needs and wishes, designers themselves play a critical role in this process. Thus, it is designers' responsibility to examine themselves. Their examination can range from their knowledge level to their interpretation of their life experiences. As designers can examine themselves in many aspects, based on the literature, we have identified five objects. These five objects are knowledge and skills related to the design task (Dewey, 1933; Simon, 1973), related experiences (Boud et al., 1985; Visscher-Voerman & Procee, 2007), feelings (Boud et al., 1985; Dewey, 1933; Schön, 1983), attitudes (Boud et al., 1985; Dewey, 1933), and ingrained beliefs and values (Mezirow, 1991).

Reflecting upon Artifacts

In design, there is an entangled relationship among designers, artifacts, and users. Artifacts are designed for human use and they are designed by designers. Designers dominate the functions of the artifact, but their decisions should be informed by the needs and preferences of users (Maier & Fadel, 2009). As design problems are ill-structured, much information is not given at the beginning of the design process. To determine the goal of the project, designers need to explore the constraints and criteria as well as to observe users' operation of similar products to determine the goal of the projects (Jonassen, 2008; Norman, 1996). Moreover, Schön (1987) argued that when solving design problems, designers "listen" to situations' "back-talk" that results from previous actions, which indicates the necessity of examining the context where the product is used. Jonassen (2008) also maintained that "successful design must address the constraints imposed by the context" (Jonassen, 2008, p.24). To design a high-quality artifact, it is imperative for designers to reflect on three objects in the artifact category, including product functions (Jonassen, 2008; Mostow, 1985; Norman, 2004), stakeholders' perspectives (Cross, 2000; Lawson, 1997; Newstetter & McCracken, 2001), and the context in which a product is operated (Asimow, 1962; Jonassen, 2008; Krick, 1969; Norman, 1996).

Reflecting upon Circumstances

When dealing with real-life design projects, designers' decisions are usually controlled by the circumstances of the design tasks. Jonassen (2008) demonstrated that designers in practice usually take into account the following factors during a design process: available technologies, available funds and talents, and the rules or politics in organizations. A designer's performance can also be affected by available time as well as budget (Eide et al., 2002). Design activities are always constrained by the project management issues, such as allocating budget and tracking progress. These tasks often consume a significant amount of practicing designers' time (Kenny, Zhang, Schwier, & Campbell, 2005), which highlights how the designers' endeavor to reflect upon these circumstances will influence their design processes.

Table 3.1
Categories and Factors for Dimension II

Category	Self	Artifact	Circumstance
Factor	(1) Knowledge (2) Experiences (3) Feelings	(1) Goals (2) Stakeholders (3) Contexts	

	(4) Attitudes
	(5) Ingrained Beliefs and values

Dimension III: Levels of Reflection

The other aspect that is equally important for understanding designers' reflective thinking is to examine the levels of their reflection. In this dimension, Argyris and Schön's idea of single-loop learning and double-loop learning (1978) as well as Flood and Romm's triple-loop learning (1996) are considered in investigating the level of designers' reflection. With the single-loop reflection, designers look for strategies or solutions to achieve a pre-defined goal. It enables designers to examine and explore alternative actions or solutions based on the criteria of efficiency and effectiveness to correct the errors and further reach the pre-identified goal (Argyris & Schön, 1978; Usher & Bryant, 1989). As for the double-loop reflection, Argyris and Schön (1978) claimed the importance of reflecting upon the designers' defined goals, functions, criteria, and constraints. This examination leads designers to question their assumptions on the design problem (Mason, 2008). Finally, designers' reflection is further expanded to take into account broader issues such as social, cultural, economical, historical, and political influences on a design process (Mezirow, 1990; Moallem, 1998; Van Manen, 1977). The triple-loop reflection drives designers to reach out from themselves and from the culture in which they reside. This level of reflection will result in a series of cascading changes in a design process and the final design may arrive at large-scale transformation for our society.

Instrument Development

The development of the questionnaire had four phases. A summary of the process is presented in Table 3.2. In the first phase, 96 items were developed based on the three-dimensional framework. After the items were developed, the goal of the second phase was to reduce and revise these 96 items. The first version of the questionnaire was tested with twelve participants from an instructional design course, and a follow-up interview was conducted with five volunteer participants to identify confusing and repetitive items. At the conclusion of the second phase, 52 items were retained. In the third phase, the second version of the questionnaire was tested with 22 participants who have completed either computer programming design or instructional design projects. The properties of the questionnaire were examined by computing Cronbach's alpha values for each scale to determine its reliability and by calculating factor analysis for confirming whether items contributed to their intended scales. Additionally, the content validity was also performed by two experts to verify the content of the items and to avoid double-barreled items. One expert was from the instructional design field and the other one was from the engineering design field. The examination in the third phase allowed us to keep 50 items.

Table 3.2
Process of Developing the RTSDP Questionnaire

Phase	Number of items	Participants	Data collection	Data analysis
1	96	• Developing items for the RTSDP questionnaire based on the three-dimensional framework		
2	52	• Participant number: 12 • Discipline: (1) Instructional Technology	• Interview • RTSDP questionnaire	• Grounded theory • Exploratory factor analysis for Dimension II & III • Cronbach's alpha for Dimension II & III
3	50	• Expert number: 2 • Participant number: 22 • Discipline: (1) Instructional technology (2) Computer science	• Expert review • RTSDP questionnaire	• Content validity • Exploratory factor analysis for Dimension II & III • Cronbach's alpha for Dimension II & III
Pilot-Test	46	• Participant number: 153 • Discipline: (1) Instructional technology (2) Engineering (3) Mechanical engineering (4) Computer science	• RTSDP questionnaire	• Inter-rater reliability for Dimension I • Exploratory factor analysis for Dimension II & III • Cronbach's alpha for Dimension II & III

The 50 items in the third version of the questionnaire were pilot-tested with 153 participants. The third version of the RTSDP questionnaire is demonstrated in Appendix 3.A. The participants were recruited from multiple courses that involve engineering design, instructional design, residential area design, and computer programming design tasks. All participants were required to complete a design project before taking the questionnaire. The questionnaire was composed of 46 items (2 items for Dimension I, 32 items for Dimension II, and 12 items for Dimension III). For Dimension I (timing), investigating when participants exercise reflection, we identified two design approaches (i.e., problem-driven and solution-driven approaches) that most designers adopt. The distinctive design stages for these two approaches were further recognized. When responding to the questionnaire, the participants were first prompted to choose their design approach and then were directed to assess the frequency of their reflection for each design stage in their selection. To confirm that participants have selected the design approach that was genuine to their design processes, participants were asked to write a description demonstrating their design processes and a rater was recruited to review the description. The inter-rater reliability between the participants' choices and the reviewer's rating of the participants' description was calculated. Based on the result, a discrepancy between these two scores existed. Thus, we abandoned the idea of requiring participants to select the design approach they adopted. Instead, from the literature, we identified six design stages that are commonly shared by designers. With these six design stages, participants are able to rate how frequently they exercise reflection. In addition, we created another new item to assess how often participants engage in reflection for three different time points during a design process (i.e., beginning, middle, and toward the end).

A total of 32 items were presented in Dimension II to examine the objects that participants reflect upon. Dimension II has three categories (i.e., self, artifacts, and circumstances). Under the categories of self and artifacts, six items were revised as a result of the low Cronbach's alpha values and low loading values from the result of exploratory factor analysis. Moreover, another six items were re-written due to the lack of clarity in the original presentation. For the category of circumstances, the eight items were originally developed to capture various aspects of circumstantial issues that designers may encounter in a design process. However, the large variations in the identified aspects might complicate the understanding of designers' reflection and result in ineffective exploration of designers' reflection on the circumstances of design tasks. Accordingly, four aspects related to the circumstances that are commonly dealt with by designers were retained. These aspects include reflection on available time, allocated budgets, equipment resources, and human resources. After the revision, 28 items were kept in this category.

For Dimension III, most items have achieved the acceptable level of internal consistency and are loaded well on the intended levels of reflection. However, there were two items that needed modification because they did not load well on their intended levels of reflection. To avoid the misinterpretation from participants, these two items were revised.

After making all necessary revisions due to the low statistical results from the Pearson's correlation coefficients, Cronbach's alpha values, and exploratory factor analysis, items were examined again for the use of language and the clarity of expression. Minor revisions were made to ensure the quality of the RTSDP questionnaire.

Purpose of the Study

The purpose of the current study is to confirm the quality of the newly developed RTSDP questionnaire for evaluating designers' reflection. A purposeful sample was selected to provide general patters of reflection among undergraduate engineering and instructional technology graduate students while they performed design tasks.

Methods

Participants

For this study, 107 students from four different courses in instructional technology and engineering fields were recruited from two universities in the Southeast region. Participants were required to complete a design project as one of their course requirements. Immediately after the conclusion of their design projects, participants were provided with the questionnaire. Participants in *Learning Environment Design* and Creative Decisions and Design completed the questionnaire during the class period, while the participants in *Instructional Design* and *Engineering Graphics and Design* finished the questionnaire outside of the class period. The list of the participants' information is summarized in Table 3.3.

Table 3.3
List of Participants

Course Title	Design Project	Graduate or Undergraduate	Number
Learning Environment Design	• Learning environment design	Graduate	15
Instructional Design	• Instructional design	Graduate	8
Engineering Graphics and Design	• Water Quality Grab Sampler • Convertible Vegetable Cage • Hands Free Crutch • Recycling and Composting System	Undergraduate	45
Creative Decisions and Design	• Water Delivery System Design	Undergraduate	38
Total			107

Instrument

Dimension I: Timing of Reflection

To capture the times that designers engage in reflection, two methods are employed. One way is to examine the time period when designers reflect more intensively. Three time points were identified. For instance, if a design project requires a six-week class period, the participants are asked to assess the frequency of their reflection that occurred during the first two weeks, the third and fourth weeks, and the last two weeks. The other way is to capture which of the six design stages the designers exercise more reflection. These stages, recognized from the literature, are identifying a goal, gathering information, defining a problem, generating solutions, evaluating solutions, and making decisions. Both aspects are assessed with the scale from one (Never) to five (Always). The items are shown in Appendix 3.B.

Dimension II: Objects of Reflection

This dimension, investigating the objects that participants reflect upon, comprises 28 items. Reflection upon self, artifacts, and circumstances are the three categories in this dimension. Three items are presented to examine designers' reflection on the categories of self and artifacts. There are 15 items in the self category and nine items in the artifact category. The last category is reflection upon circumstances, and four items are presented. All items are evaluated with a five-point scale ranging from one (Never) to five (Always). The items are shown in Appendix 3.B.

Dimension III: Levels of Reflection

The last section of the questionnaire requires participants to self-evaluate how frequently different levels of reflection are achieved when solving design problems. Three levels of reflection are generated: single-loop, double-loop, and triple-loop reflection. Four items are developed for each level. Participants are provided with a five-point scale ranging from one (Never) to five (Always). In total, twelve items are designed to explore the level of participants' reflection (See Appendix 3.B).

Data Analysis

After data collection, data were entered into Microsoft Excel and were analyzed with SPSS for Windows Version 16.0. Since the three dimensions are conceptually independent, the validation of the questions for each dimension was performed separately. For Dimension I, the reliability of the two questions was examined with test-retest reliability by computing Pearson's correlation coefficients. The test-retest reliability measures how consistent an assessment is over time (Aiken, 2000). The same questions in Dimension I were rated twice. The RTSDP questionnaire was administered the first time immediately after participants completed the design. The retest was given to participants two weeks after the first test, and only the two questions were provided.

The final version of the items in Dimension II and III was attained by reducing the items and by confirming the internal consistency based on Cronbach's alpha values and the construct validity with exploratory factor analysis. The reduction of the items was conducted by following two criteria. The items with a factor loading of at least 0.50 within their own scale were retained, and items with multiple cross-loadings were deleted. The Cronbach's alpha test was computed to ensure that all items measure the same construct. The exploratory factor analysis was conducted to inspect whether the items load well in their intended construct. The summary of validation methods for each dimension is presented in Table 3.4.

In addition, to explore the reflection patterns of participating students, the descriptive statistics of participants' frequency of reflection at each design stage and at each time period was performed. Also, the frequency of their reflection on each identified objects and three levels of reflection were also calculated.

Table 3.4
Summary of Validation Methods

Dimension	Validation Method
Timing	1. Pearson's correlation coefficient
Objects	1. Cronbach's alpha 2. Exploratory factor analysis (Principle component analysis)
Levels	1. Cronbach's alpha 2. Exploratory factor analysis (Principle component analysis)

Findings and Discussions

Reliability and Exploratory Factor Analysis

Dimension I: Timing of Reflection

The verification of the two items in Dimension I is examined with the test-retest reliability measure by computing Pearson's correlation coefficients. The retest was collected two weeks after the semester, and a total of 31 responses were received. The correlation coefficients for each design stage between the first test and the second test range from .332 to .592 (see Table 3.5). Among these design stages, the correlation for the two design stages (i.e., identifying the goal and defining the problem) achieved a moderate level. The positive correlation between two tests for defining the problem is significant at the 0.05 level. The correlation for the other four design stages (i.e., gathering information, generating solutions, evaluating solutions, and making decisions) received a strong level of reliability. The positive correlations between two tests were significant at the 0.01 level. For the items that examine the frequency of participants' reflection during each design period, the correlation coefficients between two tests range from .505 to .696 (see Table 3.5) for three design periods. A strong level of correlation for each of the three time periods was observed. Based on the correlation coefficient result, the two items in this dimension are concluded to be able to reliably measure the times that designers engage in reflection during the design process. Furthermore, these items were previously reviewed by the two experts. The content validity was confirmed to capture designers' timing of reflection.

Table 3.5
Test-retest Reliability for Dimension I

	Design Stage						Design Period		
	IG	GI	DP	GS	ES	MD	P1	P2	P3
Correlation	.332	.485**	.390*	.592**	.492 **	.496**	.513**	.505**	.696**

Notes: IG = Identify a goal; GI = Gather information; DP = Define the problem; GS = Generate solutions; ES = Evaluate solutions; MD = Making decisions; P1 = Period 1; P2 = Period 2; P3 = Period 3

Dimension II: Objects of Reflection

To validate the items in Dimension II, a reliability test was performed by calculating the Cronbach's alpha values, and the exploratory factor analysis was conducted by using the principal component analysis. The result is presented in Table 3.6. For the self category, based on the exploratory factor analysis, five factors were obtained as discussed in the theoretical framework. A total of 13 items were kept in the final version of the RTSDP questionnaire. The total variance explained is 73.25%. The Cronbach's alpha values for these five factors were 0.63 (knowledge), 0.78 (experiences), 0.75 (feelings), 0.74 (attitudes), and 0.73 (ingrained beliefs and values). The overall alpha value for the self category is 0.83.

For the category of artifact, three factors were identified based on the eigenvalues. The Cronbach's alpha values for the three factors were 0.37 (goal), 0.52 (stakeholders), and 0.54 (contexts). The overall alpha for the artifact category is 0.68. The last two factors reached the acceptable level of internal consistency, whereas a low Cronbach's alpha value was obtained for the goal factor. One of the items, investigating designers' reflection on the goal identification, received a low factor loading. Instead, this item loaded better on the factor of contexts. Nevertheless, according to the pilot test of the questionnaire, the items in the goal factor have reached an acceptable level of internal consistency and loaded well to the goal factor. The result of the formal test was not consistent with that of the pilot test. Even though the discrepancy between the two tests exists, the items should be valid for assessing designers' reflection on the goal of artifacts, especially because the face validity of the items was already confirmed by the experts in the development stage. However, it is still necessary to re-confirm the quality of the items by conducting further testing and modifications.

Table 3.6

Cronbach's Alphas and Exploratory Factor Analysis for Dimension II

Factor		Item	Loading	Reliability
SELF Knowledge	2	I examined whether I am proficient in using the tools I selected to deal with this design task.	.911	.633
	14	I examined the appropriateness of the relevant knowledge that I used for this design project.	.630	
SELF Experience	3	I considered the lessons I learned from the difficulties I encountered in my previous design experiences.	.730	.775
	6	I considered the applicability of ideas from my previous design tasks.	.858	
	16	I referred back to my previous experiences to solve this design problem.	.856	
SELF Feelings	5	I checked how I felt in relation to my design progress.	.730	.748
	8	I paid attention to my feelings during the design process.	.849	
	15	I was aware of any emotional change caused by the design progress.	.807	
SELF Attitudes	9	I examined my level of commitment to this project.	.703	.738
	10	I checked my level of open-mindedness while completing the project.	.835	
	13	I examined my level of responsibility during the design process.	.796	
SELF Ingrained Beliefs & Values	11	I discovered inaccurate personal beliefs, which I had previously believed to be right.	.907	.727
	12	I challenged my beliefs established throughout my life (for example, personal experiences, environments, and upbringing).	.789	
ARTIFACT Goals	7	I evaluated whether the constraints I found are important to define the problem.	.928	.370
	17	I examined whether the goals I identified could improve the problematic situation.	.162	
ARTIFACT Stakeholders	4	I considered my end users' needs while designing the product.	.822	.521
	19	I took into account the end users' preferences while designing the product.	.752	
ARTIFACT Contexts	1	I assessed the product feasibility based on its intended setting.	.578	.538
	18	I evaluated whether the end product will be used in its intended setting based on my identified goal.	.798	
CIRCUMS TANCES	20	I evaluated if I utilized the budget wisely.	.795	.659
	21	I examined if I used the available resources (for example, machines, equipment, or software) effectively.	.821	
	22	I examined if I used the human resources properly.	.731	
	23	I assessed if I managed the time appropriately.	.439	

Notes: overall α for the category of self =.832; overall α for the category of artifacts =.687

The last category in this dimension is to examine designers' reflection on circumstances. Based on the result of the exploratory factor analysis, there is one eigenvalue that is greater than one. Thus, only one factor was extracted in this category. The Cronbach's alpha value for this factor reached 0.66, which indicates an acceptable degree of internal consistency among the four items. However, one item, investigating designers' reflection on their time management, has a factor loading that is slightly lower than 0.5. Statistically, according to the criteria, the item should be omitted, but it is retained. As all class projects have deadlines, students have immediate time pressure. Failing to complete projects by the due date would have a direct impact on their scores for the courses. On the other hand, participating students might spend less effort considering other aspects, such as budget allocation, human resources, and equipment resources. Their poor use of budget or resources might not lead to direct feedback or consequences in terms of their scores. For example, one of the engineering design projects requires students to propose a budget plan. Even though students dealt with the class project that simulates real world design tasks, students might not interpret this assignment as being as important as their time management. Accordingly, less reflection on these aspects is yielded, and the discrepancy of participants' reflection frequency on time management and on other aspects is observed. Therefore, it is reasonable to keep the item of reflection on time management for examining designers' reflection on circumstances.

Dimension III: Levels of Reflection

The validation of the items in Dimension III was conducted by the same measures as the Dimension II. This dimension consists of three factors (i.e., single-loop reflection, double-loop reflection, and triple-loop reflection). The construct validity of the items was examined by using exploratory factor analysis. The eigenvalues of the three factors were all larger than one, while two items with a factor loading of less than 0.50 and with many cross-loadings were omitted from the questionnaire. The final version of the questionnaire has 10 items in this dimension. The reliability was checked with the Cronbach's alpha values. All three factors reached an acceptable level of internal consistency. The reliability coefficients were 0.61, 0.77, and 0.78, respectively, and the overall alpha was 0.77, suggesting these factors had sufficient reliability to measure the levels of designers' reflection. Results of the reliability and validity tests are presented in Table 3.7.

Table 3.7
Cronbach's Alphas and Exploratory Factor Analysis for Dimension III

Factor		Item	Loading	Reliability
SINGLE-LOOP	2	I examined whether I completed the design efficiently.	.641	.611
	4	I checked whether my solution was effective in achieving the project goal.	.837	
	10	I evaluated whether the solution satisfied the specified goal of the project.	.738	
DOUBLE-LOOP	3	I re-examined my assumptions on the design project to refine the definition of the problem.	-.822	.766
	6	I re-inspected my previous understanding of how I define the problem.	-.849	
	8	I examined why I believed the defined goal was critical to address the problem.	-.774	
TRIPLE-LOOP	1	I evaluated whether my design attends to the needs of people of all ethnic backgrounds.	.800	.776
	5	I assessed whether my end product caters to the needs of people from different socio-economic groups.	.735	
	7	I considered social injustice issues when making decisions to my design.	.816	
	9	I contemplated ethical concerns relative to my design task.	.732	

Notes: overall α =.765

Novice Designers' Reflection Patterns

With participants' responses to the RTSDP questionnaire, the average scores and standard deviations for each factor were computed to obtain the reflection patterns of participating students. The participants from four courses were categorized into two groups. The first group consists of participants taking graduate-level courses in instructional technology, and the participants in the second group were undergraduate engineering students. For Dimension I, the results show the timing when the participating students exercise their reflection during their design processes (See Figure 3.2). The instructional technology graduate students reflected more intensively when identifying goals, gathering information, and making decisions. The mean scores of the frequency of their reflection occurring at these three design stages were 3.86, 3.83, and 3.98. On the other hand, the engineering undergraduate participants reflected more intensively on generating solutions, evaluating solutions, and making decisions (average scores of 3.89, 3.78, and 3.70). The engineering undergraduate students demonstrated more reflection in the design stages that is related to solutions, whereas participants in instructional technology exerted more effort to identify the goal.

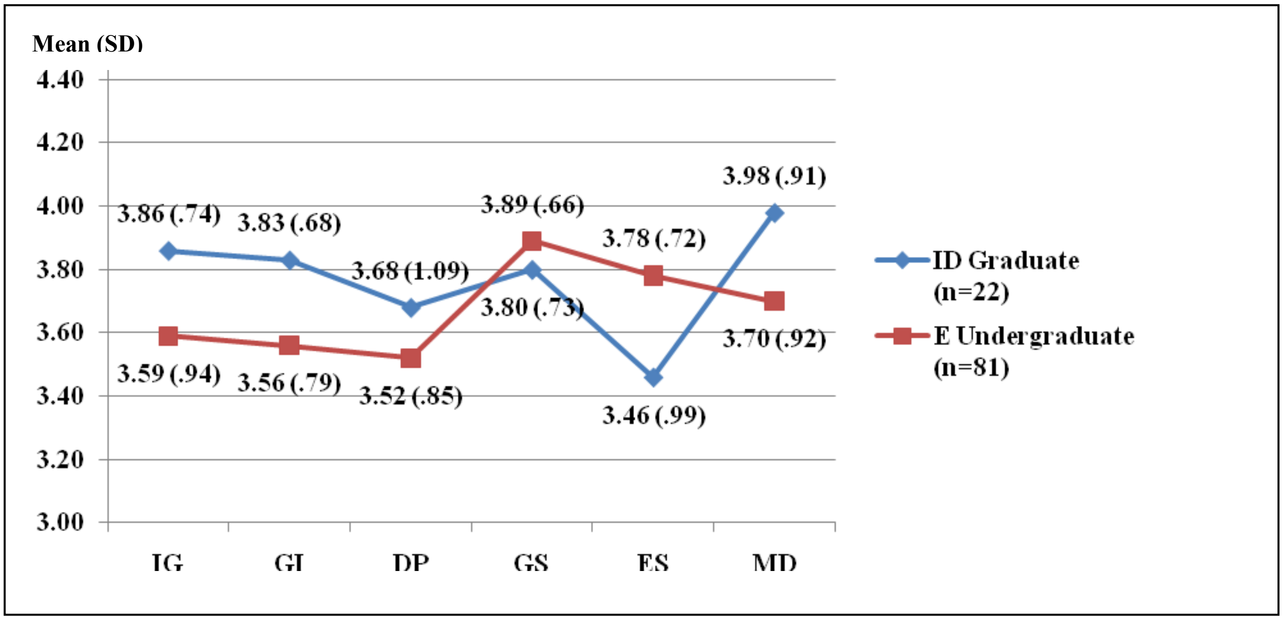

Figure 3.2. Participants' frequency of reflection at each design stage.
Notes: IG = Identify a goal; GI = Gather information; DP = Define the problem; GS = Generate solutions; ES = Evaluate solutions; MD = Making decisions

With regard to the frequency of participants' reflection at each time period, the results are presented in Figure 3.3. Participants in both groups have increased the frequency of their reflection as they approached the due dates of the design projects. The mean scores of participants' reflection toward the end of the project were 4.06 and 3.79 respectively for the instructional technology graduate students and the engineering undergraduate students. However, the average scores of their reflection at the beginning of the project were 3.44 for instructional technology students and 3.51 for engineering students. Two reasons may explain the phenomenon of students' more intensive reflection toward the end of the project. One reason may be that students invested more time in the project when approaching the deadlines because incomplete or poor quality projects would result in poor performance evaluation. The other reason may be that students do not have sufficient experience in performing design tasks, so they did not know what to reflect upon. As it is critical to guide students to reflect at an early stage of their design processes (Valkenburg & Dorst, 1998), more in-depth investigation is needed to determine the appropriate strategies for promoting students' reflection.

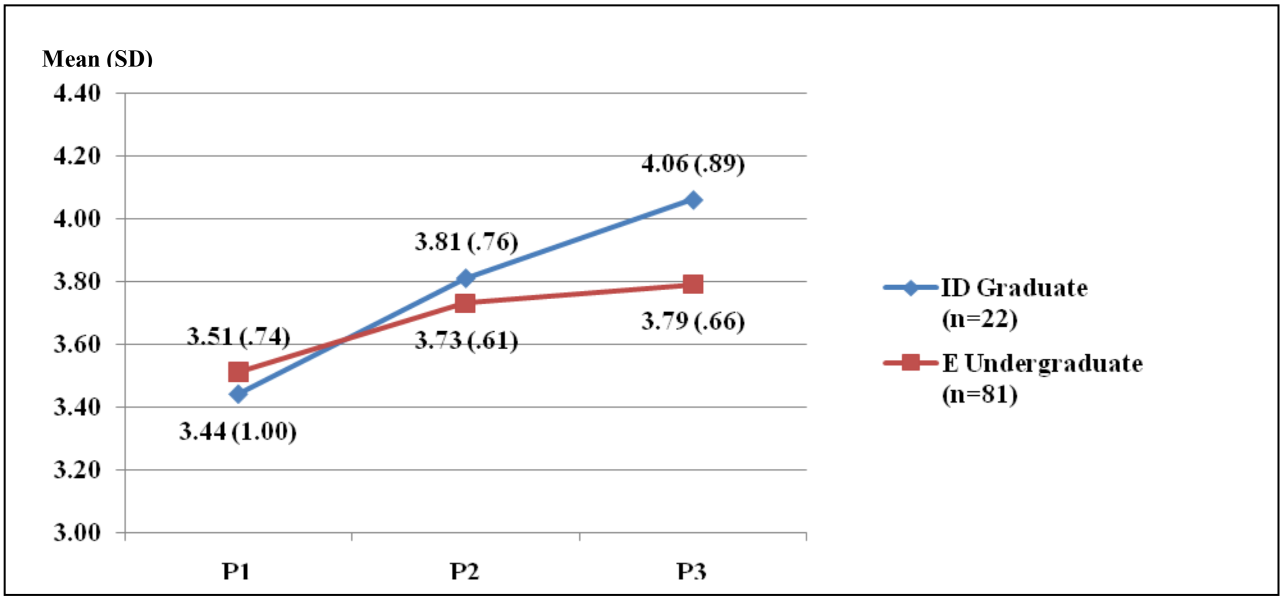

Figure 3.3. Participants' frequency of reflection during each design period.
Notes: P1 = Period 1; P2 = Period 2; P3 = Period 3

According to participants' responses to the items in Dimension II, the graduate students in instructional technology indicated that they usually reflected on the following objects: their own knowledge, their previous experiences, their attitudes, stakeholders of the artifact, and contexts of the artifact. The mean scores of their reflection on these items range from 4.15 to 4.56 (see Figure 3.4). Among these objects, they engaged in reflection less frequently on their ingrained beliefs and values (an average score of 2.69). For the objects that the undergraduate engineering participants reflected upon, they rated themselves as exercising more reflection on the goals, the stakeholders, and the contexts of the artifact (respective average scores of 4.11, 4.30 and 4.20) and less reflection on their own feelings and their ingrained beliefs and values (average scores of 2.76 and 2.16). Based on the results, the instructional technology graduate students showed balanced reflection on most of the identified objects, but less reflection on ingrained beliefs and values. The undergraduate engineering students, on the other hand, engaged in more intensive reflection on the artifact, and they reflected less on themselves. The finding may suggest that the undergraduate engineering students need particular strategies to engage them in reflecting on the aspects that fall in the self category.

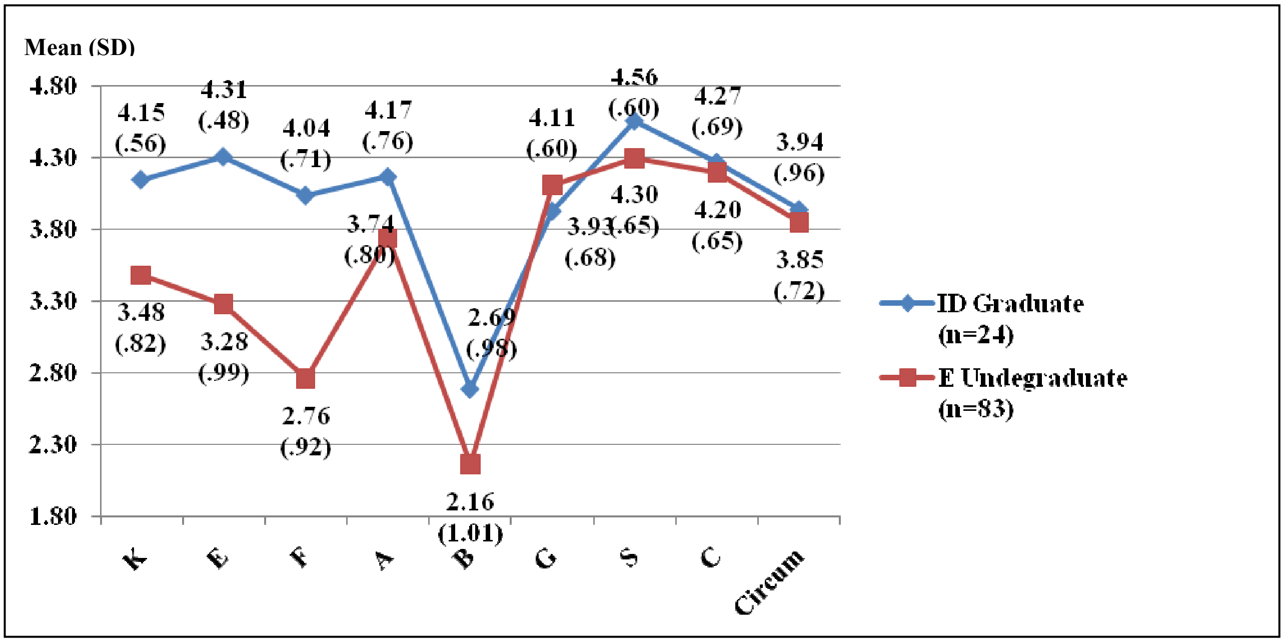

Figure 3.4. Participants' frequency of reflection on each object.
Notes: K = Knowledge; E = Experience; F = Feeling; A = Attitude; B = Ingrained beliefs and values; G = Goal; S = Stakeholder; C = Context; Circum = Circumstances

In the examination of participants' levels of reflection, both groups of participants reflected more heavily at the single-loop level and the least frequently at the triple-loop level. The average score of the instructional technology graduate students reflecting at the single-loop level is 4.31 and that of undergraduate engineering students is 4.35 (see Figure 3.5). On the other hand, the frequency of their triple-loop reflection is relatively lower than their reflection at the single-loop level. The mean score of the instructional technology graduate students' reflection at the triple-loop level is 2.91 and that of engineering undergraduate students is 2.32. This result indicates that participating students were inclined to focus on searching for the solutions to satisfy the already established goals, and they seldom challenged their understanding and interpretation of a design task.

With the results that demonstrate the participants' levels of reflection, the next step in this line of research is to investigate whether the higher level of reflection leads to better design performance. Such investigation will guide educators to identify instructional strategies that will help promote designers' reflection and further improve their ability in solving design problems.

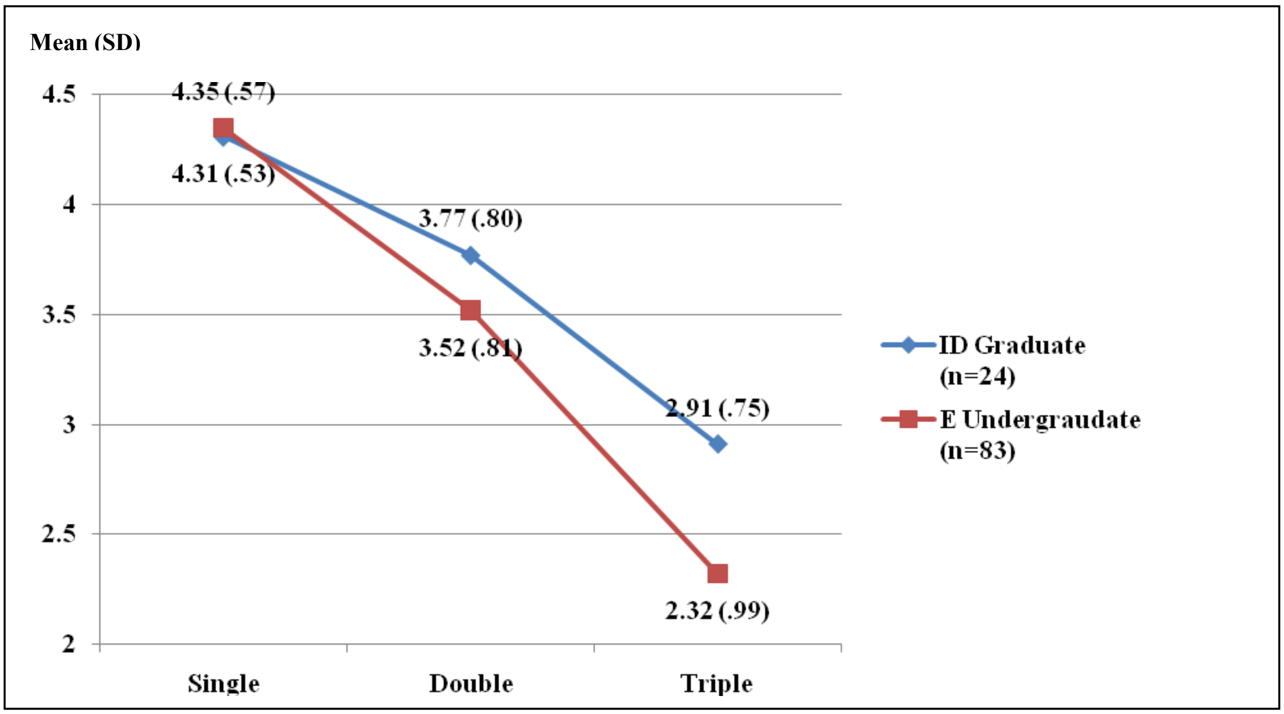

Figure 3.5. Participants' frequency of reflection for each level.

Conclusions and Implications

The purpose of the paper was to develop and validate a new questionnaire, Reflective Thinking in Solving Design Problems, that examines designers' reflection occurring during a design process. The questionnaire consists of three sections that probe into designers' reflection in three dimensions: the timing of reflection, the objects of reflection, and the levels of reflection. The validation results for most sections indicated that the RTSDP questionnaire in this study had reached the acceptable level of validity and reliability, with the exception of the items that are used to examine designers' reflection on how they identify the goals of the artifacts. In the formal test, the reliability measure for the goal factor failed to show the internal consistency and one item did not load well to its intended factor. However, in the development stage, the face validity of the items was confirmed by the experts. In addition, the items in the pilot test have reached acceptable reliability and validity measures. The discrepancy might be the result of different design projects that were assigned to the participants and the different composition of participants in the pilot and formal tests. To ensure the quality of the items, further testing is needed.

The RTSDP questionnaire responses provide information for educators and researchers in the field of design about the reflection patterns of students performing instructional design and engineering design tasks. Based upon the results of participants' reflection patterns, the instructional technology graduate students exerted more reflection when they were in the process of identifying the goal, gathering information, and making decisions, while the engineering undergraduate students focused more on generating and evaluating solutions as well as making decisions. With regard to the design period that participants engaged in reflection, participants from both groups indicated that they reflected more heavily toward the end of the design processes. Among the identified objects of reflection, the results show that participants in the graduate-level instructional design courses have more balanced reflection on various objects. When comparing the different objects they have reflected upon with their counterparts, the instructional design graduate students yielded more reflection on their selves. On the other hand, the undergraduate engineering participants reflected more heavily on the objects related to artifacts. As for the levels of reflection, participants in both groups rated their reflection the most frequently at the single-loop level and the least frequently at the triple-loop level. With the RTSDP questionnaire, educators are able to understand students' reflection patterns when they perform design tasks.

As we have demonstrated in this paper, the RTSDP questionnaire has value as a diagnostic tool to help educators and researchers in design to understand when, what, and how designers engage in reflection. Due to the complicated and intangible nature of designers' reflection occurring during a design process, the use of the RTSDP questionnaire can help educators and researchers capture the reflection patterns of individual students. The discovery of students' reflection can be used in two ways. First, it can guide educators and researchers to design reflective learning environments that improve students' abilities in solving design problems. Second, it can also help students themselves to be aware of their reflection patterns and direct their attention to the aspects of reflection that they have overlooked during their design processes.

Prior to the design and development of reflective learning environments, the RTSDP questionnaire can be used by the educators and researchers for two types of research, and the results of that will further inform the design of reflective learning environments. First, with the RTSDP questionnaire, researchers can conduct comparison studies that investigate the different reflection patterns between novice and expert designers. According to Rowland's (1992) observation, novice designers interpreted the given instructional design task as well-defined by the given information, while expert designers regarded the task as ill-defined and questioned the given information. Moreover, Kenny and his colleagues (2005) found that practicing instructional designers invest a large amount of time in project management. However, in most projects given in class settings, project management issues are less emphasized. As the design process of expert designers is distinct from that of novice designers, their reflective patterns may be different. The use of the RTSDP questionnaire will help educators and researchers to investigate the differences, which further allow them to design a learning environment that guides novice designers to reflect in the same fashion as expert designers. The second type of research can equally inform the design of reflective learning environment for students in the field of design. The RTSDP questionnaire aims to capture designers' different timing of reflection, the objects that designers may reflect upon, and the levels of designers' reflection. The findings about designers' reflection in these three dimensions can be correlated with their design performance. The results of such study will allow educators and researchers to summarize the kind of reflection patterns that will most likely lead to a successful design. As a result, educators and researchers can use the result to design effective learning environments that support designers' reflection. Moreover, after the design and development of learning environments, educators and researchers can use the RTSDP questionnaire to investigate the effects of the learning environments that aim to support designers' reflective thinking. In the earlier discussion, various methods were identified and utilized to examine the effectiveness of the proposed instructional strategies. We believe that the RTSDP questionnaire will be an addition to the collection of research methods to confirm the effectiveness of the developed learning environments.

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Appendix 3.A.
Reflective Thinking in Solving Design Problems Questionnaire for Pilot Test

Section I. Demographic Information

1. Student ID #: ______________________
2. Age: ________________________
3. Gender: ☐ Male ☐ Female
4. Institution: ____
5. Department/Program: ____
6. Provide the course in which you took this survey (Course No.): ___________________
7. Class Standing: ☐ Undergraduate ☐ Graduate
8. Year in the program: ☐ 1st ☐ 2nd ☐ 3rd ☐ 4th ☐ 4th+
9. Experience in Design: ☐ No Experience ☐ 1-2 years ☐ 3-5 years ☐ 5-8 years ☐ 10+ years
10. Email: ____
11. Please identify the most recent project in which you were involved.
    TO ANSWER THIS SURVEY, USE THIS SPECIFIED PROJECT AS A REFERENCE.
    The title of the project that I choose to answer this survey is _______________________

Section II: When do you think reflectively?

When you design a product or a system for a project, you have your own unique approach to realize the design. Some of you conduct a comprehensive analysis of the problematic situation and gather information to define the problem before attempting to generate any solution (Fig. 1) while others come up with an initial solution, through which you discover more information of the problem so that you can continue to generate better solutions or even learn more about the problem (Fig. 2). The adoption of the design approach varies depending on the nature of the projects, designers' experiences, designers' preferences, etc.

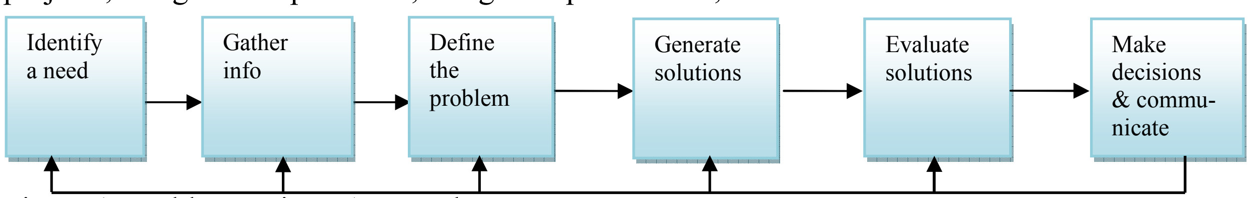


Figure 1. Problem-Driven Approach

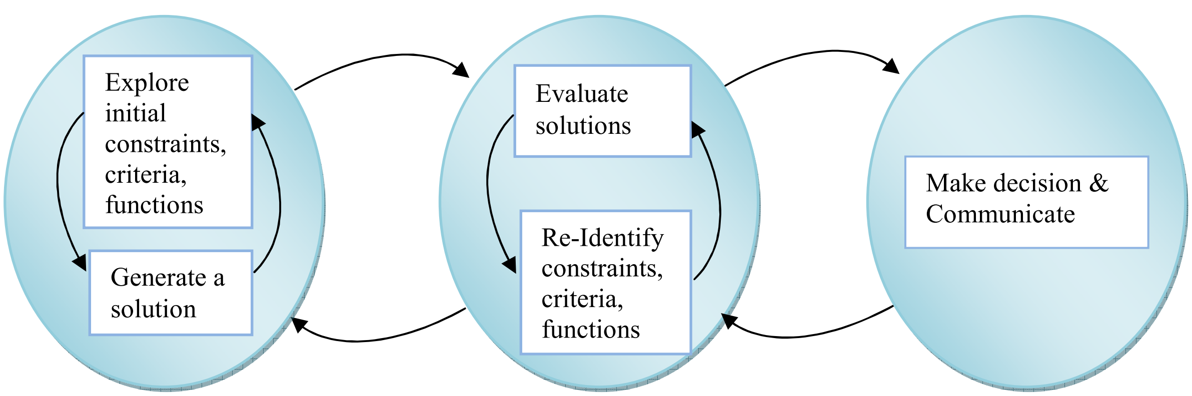
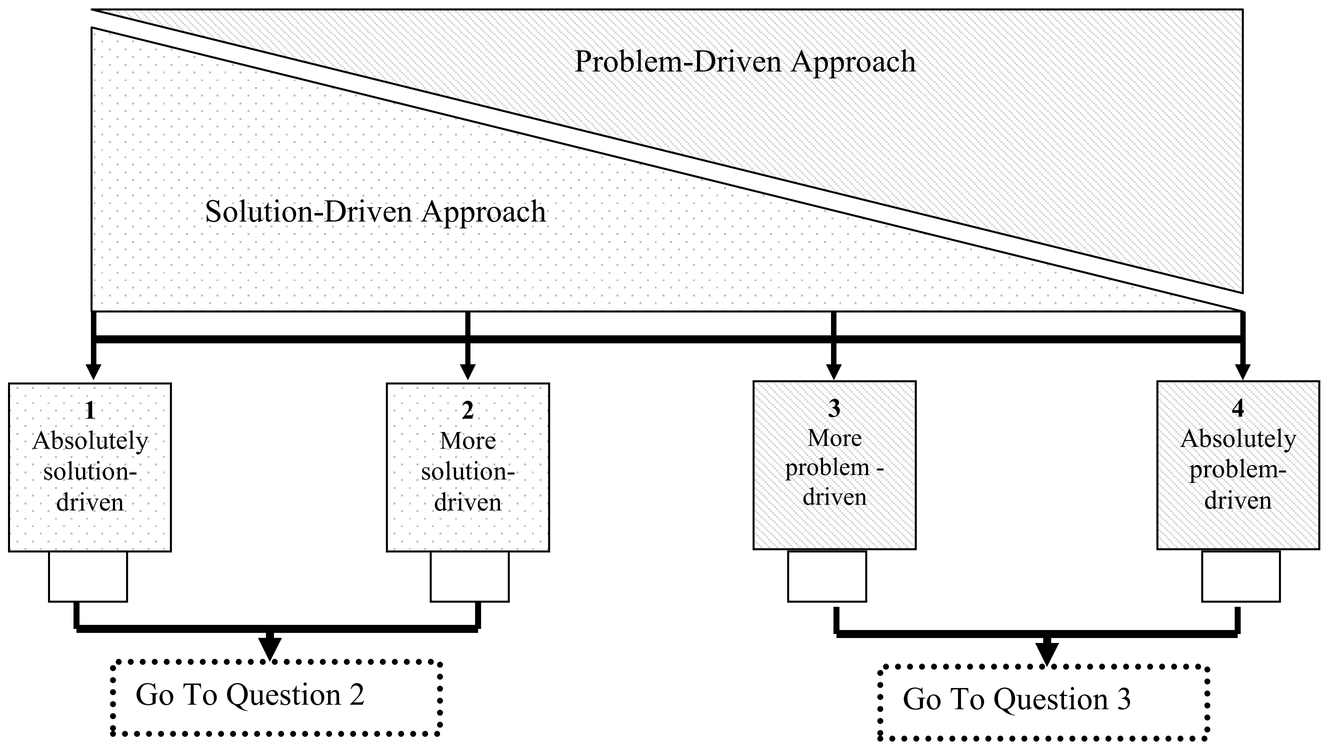


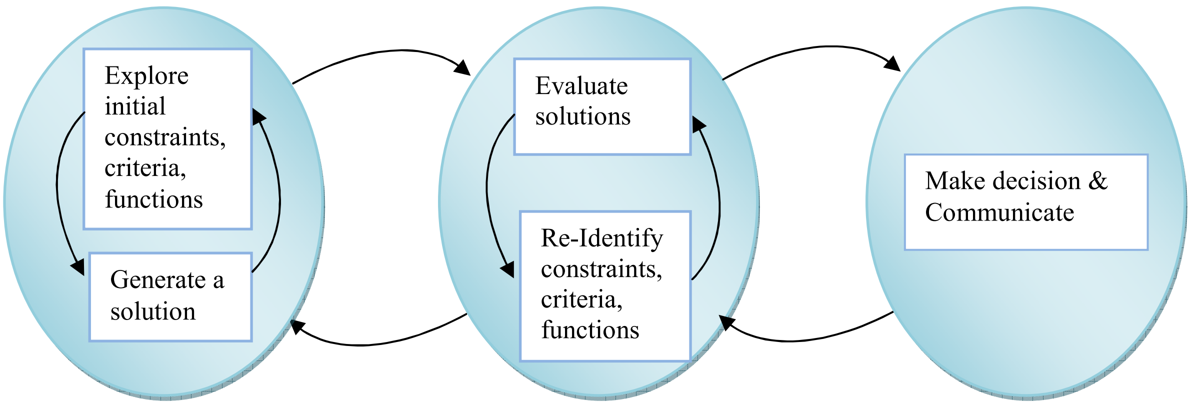
Figure 2. Solution-Driven Approach

1. After learning the problem-driven approach and the solution-driven approach from the above description and images (Fig. 1 and 2), please **CHECK** the appropriate box below that best represents the design approach you used for your previously specified design project.



2. [If you checked option **1 or 2** in Question 1]

What is REFLECTION?
When you design, you actively think about and rigorously examine your ideas, process, actions, progress, etc. With your critical examination and dedication to creating a good design, you change your thoughts and/or actions to come up with a better solution for your design project. All of deliberate efforts on your thinking and your actions are considered as an act of reflective thinking.



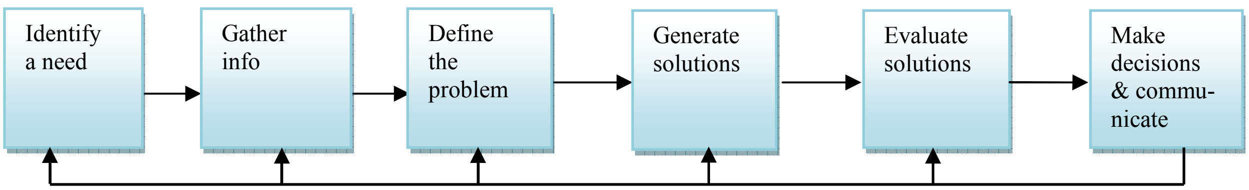
Check how frequently you reflect on the following design events.

Design Events	Never 1	Seldom 2	Sometimes 3	Usually 4	Always 5
1.Explore initial constraints, criteria, and functions					
2.Generate a solution					
3.Evaluate solutions					
4.Re-identify constraints, criteria, and functions					
5. Make decisions & Communicate					

Proceed to Section III and please DO NOT move back to previous pages

3. [If you checked option **3 or 4** in Question 1]

What is REFLECTION?
When you design, you actively think about and rigorously examine your ideas, process, actions, progress, etc. With your critical examination and dedication to creating a good design, you change your thoughts and/or actions to come up with a better solution for your design project. All of deliberate efforts on your thinking and your actions are considered as an act of reflective thinking.



Check how frequently you reflect on the following design events.

Design Events	**Never 1**	**Seldom 2**	**Sometimes 3**	**Usually 4**	**Always 5**
1.Identify a need					
2.Gather information					
3. Define the problem					
4. Generate solutions					
5. Evaluate solutions					
6. Make decisions & Communicate					

Proceed to Section III and please DO NOT move back to previous pages

Section III: What do you reflect upon?

Instruction:
Please read each statement carefully and check the option that best describes the objects you reflected upon when solving your previously specified design project. Using the scale of 1 to 5, 1 indicates a statement NEVER happened while 5 indicates a statement ALWAYS happened during your design process. Some items have NOT APPLICABLE (N/A) choice. Please choose it when necessary.

Items	Never 1	Seldom 2	Sometimes 3	Usually 4	Always 5	N/A 6
1. I took into account end users' preferences while designing the product.						⊘
2. I examined if I am proficient in using the tools I selected for dealing with this design task.						⊘
3. I considered the lessons learned from my mistakes in my previous design experiences.						⊘
4. I carefully considered my end users' needs to process my design.						⊘
5. I checked if I have enough relevant knowledge to deal with this task.						⊘
6. I consciously checked how I felt in relation to my design progress.						⊘
7. I used solutions from my previous design tasks for this design project.						⊘
8. I evaluated if the constraints I found are important to define the problem.						⊘
9. I was aware of my positive emotion in relation to my design project.						⊘
10. I was aware of the level of commitment I put in this design project.						⊘
11. I consciously examined if I was open to different opinions when dealing with this design task.						⊘
12. I discovered inaccurate personal beliefs, which I had previously believed to be right.						⊘
13. I challenged my beliefs established throughout my own life (for example, personal experiences, environments, and upbringing).						⊘
14. I checked if I was responsible enough for providing the best possible solution.						⊘

Items	Never 1	Seldom 2	Sometimes 3	Usually 4	Always 5	N/A 6
15. I examined if I appropriately used the relevant knowledge to deal with this design project.						⊘
16. I examined my contribution to the society as a designer.						⊘
17. I examined where my frustration comes from when I faced difficulties.						⊘
18. I assessed the appropriateness of the criteria that I used to identify the goal.						⊘
19. I pondered over my clients' requests during my design.						⊘
20. I assessed the time needed for developing the product while I designed.						
21. I examined if the goals I identified could improve the problematic situation.						⊘
22. I assessed if the product is appropriately used in the intended context.						⊘
23. I examined if I used the available resources (for example, machines, equipment, or software) effectively.						
24. I examined various contextual aspects (for example, social, economical, cultural, historical) in relation to my design project.						⊘
25. I paid close attention to the use of the budget.						
26. I considered how the environment could be changed by the use of my product.						⊘
27. I dealt with the influences of group dynamics within my organization/class on the decisions that I made during the design process.						
28. I assessed if I allocated time appropriately for different design stages.						
29. I referred back my previous successful experiences to solve this design problem.						⊘
30. I assessed the capacity of my team for making appropriate decisions.						
31. I examined how the physical environment interacts with my design performance.						
32. I examined if I used the human resources properly.						

Proceed to Section IV and please DO NOT move back to previous pages

Section IV: What is the level of your reflection?

Instruction:
Please read each statement carefully and choose the option that best describes the level of your reflection when solving your previously specified design project. Using the scale of 1 to 5, 1 indicates a statement NEVER happened while 5 indicates a statement ALWAYS took place in your design process.

Items	Never 1	Seldom 2	Sometimes 3	Usually 4	Always 5
1. I re-evaluated if the criteria and constraints that I used for determining the goal are appropriate.					
2. I evaluated whether or not my design attends to the needs of the people in all ethnic backgrounds.					
3. I examined whether or not I completed the design efficiently.					
4. I examined if the already identified goal could fix the root cause of the problem.					
5. I evaluated if my strategies efficiently help me reach the identified goal.					
6. I checked whether or not my solution was effective in achieving the goal of the project.					
7. I assessed whether or not my end product caters the need of the people from different socio-economic groups.					
8. I re-inspected my understanding that would influence how I define the problems.					
9. I challenged my common sense beliefs that have been developed through my own life experiences.					
10. I examined why I believed the defined goal was significant to solve the problem.					
11. I contemplated ethical concerns relative to my design task.					
12. I evaluated whether or not the solution satisfied the specified goal of the project.					

Proceed to Section V and please DO NOT move back to previous pages

Section V: How did you process your design project?

In 100 – 200 words, please describe the steps/actions you took to perform your chosen design project. For instance, how did you begin this project?; what were the different steps you took to complete the design?; and how did you wrap up your design?

Thank You!!!

Appendix 3.B

Reflective Thinking in Solving Design Problem Questionnaire for Formal Test

Dimension I: Timing of Reflection

Factor	Item
Design stages	• Identify the goal • Gather information • Define the problem • Generate solution(s) • Evaluate solution(s) • Make decision(s)
Design periods	• Period 1 • Period 2 • Period 3

Note: a scale of 1 (Never) to 5 (Always) was employed.

Dimension II: Objects of Reflection

Factor		Item
SELF Knowledge	2	I examined whether I am proficient in using the tools I selected to deal with this design task.
	5	I assessed whether I have enough relevant knowledge to carry out my design.
	15	I examined the appropriateness of the relevant knowledge that I used for this design project.
SELF Experience	3	I considered the lessons I learned from the difficulties I encountered in my previous design experiences.
	7	I considered the applicability of ideas from my previous design tasks.
	20	I referred back to my previous experiences to solve this design problem.
SELF Emotions	6	I checked how I felt in relation to my design progress.
	9	I paid attention to my feelings during the design process.
	17	I was aware of any emotional change caused by the design progress.
SELF Attitudes	10	I examined my level of commitment to this project.
	11	I checked my level of open-mindedness while completing the project.
	14	I examined my level of responsibility during the design process.
SELF Ingrained Beliefs & Values	12	I discovered inaccurate personal beliefs, which I had previously believed to be right.
	13	I challenged my beliefs established throughout my life (for example, personal experiences, environments, and upbringing).
	16	I examined whether my lens of viewing the world is inclusive for people of all backgrounds.
ARTIFACT Functions	8	I evaluated whether the constraints I found are important to define the problem.
	18	I assessed the appropriateness of the criteria that I used to identify the goal.
	21	I examined whether the goals I identified could improve the problematic situation.
ARTIFACT Stakeholders	4	I considered my end users' needs while designing the product.
	19	I pondered over the stakeholders' needs during my design.
	23	I took into account the end users' preferences while designing the product.
ARTIFACT Contexts	1	I assessed the product feasibility based on its intended setting.
	22	I evaluated whether the end product will be used in its intended setting based on my identified goal.
	24	I examined how the contextual factors (for example, social, cultural, economical, historical) influenced my design decisions.
CIRCUMS	25	I evaluated if I utilized the budget wisely.

TANCES	26	I examined if I used the available resources (for example, machines, equipment, or software) effectively.
	27	I examined if I used the human resources properly.
	28	I assessed if I managed the time appropriately.

Note: a scale of 1 (Never) to 5 (Always) was employed.

Dimension III: Levels of Reflection

Factor		Item
SINGLE-LOOP	3	I examined whether I completed the design efficiently.
	5	I evaluated whether my strategies efficiently help me reach the identified goal.
	6	I checked whether my solution was effective in achieving the project goal.
	12	I evaluated whether the solution satisfied the specified goal of the project.
DOUBLE-LOOP	1	I re-evaluated whether the criteria that I used for determining the goal are appropriate.
	4	I re-examined my assumptions on the design project to refine the definition of the problem.
	8	I re-inspected my previous understanding of how I define the problem.
	10	I examined why I believed the defined goal was critical to address the problem.
TRIPLE-LOOP	2	I evaluated whether my design attends to the needs of people of all ethnic backgrounds.
	7	I assessed whether my end product caters to the needs of people from different socio-economic groups.
	9	I considered social injustice issues when making decisions to my design.
	11	I contemplated ethical concerns relative to my design task.

Note: a scale of 1 (Never) to 5 (Always) was employed.

CHAPTER 4

EXPLORING NOVICE DESIGNERS' PATTERNS OF REFLECTIVE THINKING AND THEIR DESIGN PERFORMANCE

[1] Hong, Y.C. and I. Choi. To be submitted to *Instructional Science.*

Abstract

The purpose of this study is to investigate the relationship between novices' patterns of reflective thinking and their performance in solving design problems. Reflective thinking is a critical element in the process of solving ill-defined design problems. Many educators are dedicated to finding ways to promote students' reflection, yet very few empirical studies have attempted to explore the relationship between reflective thinking and design performance. Forty-four students enrolled in the Introduction to Micro- and Nano-Biotechnology course participated in this study. Through a self-assessed questionnaire, students' reflection patterns were collected in three areas: the timing of reflection, the objects of reflection, and the levels of reflection. Also, students' performance scores in their group project on biomedical device design were collected. The results identified certain patterns of novices' reflection that yielded better performance in solving design problems. Implications for instructional strategies that promote novices' reflective thinking and enhance their problem-solving abilities in design tasks were discussed.

Introduction

Reflective thinking plays a significant role in one's learning processes and professional development (Boud, Keogh, & Walker, 1985; Dewey, 1933; Mezirow, 1990; Schön, 1983). For designers, being reflective during a design process is critical to carry out design tasks and create useful products or systems (Moallem, 1998; Rowland, 1993; Shambaugh & Magliaro, 2001). Rowland argued "design expertise is thought to lie not only in knowledge and skills, but in the designers' ability to reflect on his or her actions" (1993, p. 86). According to Richy, Field, and Foxon (2001), reflecting upon different aspects of a design situation before concluding design solutions is an essential competence that designers should possess. Schön (1983) indicated that design is a reflective conversation between the designer and the design situations, and reflection is integral in one's design process.

Reflection is a key component in performing design tasks. With continual reflection, designers are able to control their design processes, think and execute more flexibly when dealing with new design situations, and increase iterations during a design process. First, reflection enables designers to control their design processes by monitoring, evaluating, justifying, and modifying their understanding of the problems and the solutions they generate (Greeno, Korpi, Jackson, & Michalchik, 1990; Lloyd & Scott, 1994). Solving a design problem is an ill-structured task and designers need to attend to manifold aspects of design (Jonassen, 1997). Therefore, it is especially important for designers to function as a self-organizing system that consciously examines every possible aspect of the situation, tracks ongoing activities, evaluates the previous actions, and makes decisions for the next actions and strategies based on observations. Another reason that manifests the importance of engaging designers in reflection is that reflection makes designers more capable of handling new design problems. As most design problems are context-dependent and domain-specific (Goel & Pirolli, 1992; Jonassen, 2011; Rowland, 1993, Simon, 1973), it is unlikely that problem solvers can successfully solve new problems by rigidly following theories, techniques, or systematic procedures that were previously acquired from classes and textbooks (Jonassen, 2000, 2011; Schön, 1983). Instead, designers' reflection helps them to flexibly incorporate prior knowledge while improvising, inventing, and testing the solutions and their approaches based on the context of the design (Schön, 1983). Thus, reflection gives designers the capacity to examine the effects of their actions on the situation and derive new strategies for further actions depending on the situation. The third reason demonstrating the importance of reflection in design is that exercising reflection allows designers to undergo several iterations in their design processes. An iterative design takes place when designers scrutinize their understanding of a problem, which directs them to reshape the problem space and re-identify the goal. The emergent problem definition further leads to the generation of new solutions. Then, the evaluation of the proposed solutions in turn contributes to another round of problem re-definition (Adams, 2001). Reflection during a design process involves designers in appreciating the situation, reframing the problem, and generating alternatives accordingly until the proposed solution achieves a satisfactory outcome (Schön, 1987). The more iterations that occur in a design process, the more designers can improve the quality of their designs (Adams, Turns, & Atman, 2003).

Recognizing the importance of reflection in design, researchers in various design fields such as architectural design (Schön, 1983, 1987), engineering design (Adams et al., 2003; Lloyd & Scott, 1994), and instructional design (Rowland et al., 1992; Visscher-Voerman & Procee, 2007) have studied designers' reflection behaviors when solving design problems. Schön (1987) observed an architectural design student's design process and found that reflective thinking plays a critical role in helping the student move forward in his design processes. Similarly, a research study that investigated the instructional design process showed that the second most frequent behaviors during the participants' design processes are metacognitive activities, which are described as recapitulating, reflecting, evaluating, monitoring, and justifying activities (Greeno, et al., 1990). Another study conducted by Lloyd and Scott (1994) aimed to understand field engineers' design processes and revealed that designers demonstrated evaluative behaviors immediately after they generated solutions. The evidence of evaluative behaviors is designers' reflection on the design situation and the comments they made based on their experience and preference. In addition to Lloyd and Scott's study, Adams and her colleagues (2003) researched engineering design students' design behaviors. They discovered that senior engineering students iterated more frequently between problem definition and solution generation, and they made transitions among more design stages. The iterative design processes were driven by designers' reflection (Adams et al., 2003).

Existing studies in different design fields discovered that reflection behaviors are one of the activities in which successful designers frequently engage. Because of its importance in one's design process, there has been a growing interest in developing and investigating strategies or learning environments to facilitate student designers' reflection. Among a variety of strategies proposed, providing guiding questions and prompts to designers is widely used and investigated. Reymen and her colleagues (2006) developed a list of domain-independent questions that guide designers in any design discipline to reflect on the products being designed and their design process. The questions direct designers to reflect on various aspects, such as the properties of the product, the design context, the stakeholders, the goal of the design task, designers' own knowledge, and the influence of the institutional visions on the design. In the context of instructional design, Luppicini (2003) generated a list of questions, namely, Reflective Action Instructional Design (RAID). RAID was developed to guide designers to reflect on what has happened, what is happening, and what will happen when solving instructional design problems. Another study carried out by Wetzstein and Hacker (2004) revealed that designers' reflection on knowledge can be promoted by asking designers to verbally describe, explain, justify, and evaluate their design decisions to another partner. Davis and Linn (2000) studied the different prompts within the Knowledge Integration Environment learning system and found that self-monitoring prompts help students think about their goals for and progress on a design project. The self-monitoring prompts also help students reflect on their knowledge and on the connection between the previous learned knowledge and the design task. In addition to guiding questions and prompts, providing students cases is another strategy that drives designers to reflect in performing instructional design tasks (Bennett, 2010; Rowland, Fixl, & Yung 1992). As most students lack experience in design, the cases offer students vicarious experience, which helps students reflect on the perspectives they used for framing the problem, on the consideration of the circumstances of the design task, and on how they move their design forward from the beginning to the end. Rowland and his colleagues (1992) also recommended the use of cases to facilitate students' reflection and observed that the cases and the experts' modeling in the cases make students aware that every decision made in a design process should depend on the context of design tasks. Asking students to construct a video that captures the design process is another strategy for promoting reflection (McDonnell, Lloyd, & Valkenburg, 2004). This method helps students to monitor the process of their design and realize that the design can be carried out in multiple ways. Moreover, constructing a video allows students to observe the change of their feelings and later to reflect on how their feelings have changed owing to their progress and status of the design. Distinct from the strategies discussed earlier, a semester-long course in systematic reflection offers students opportunities to learn the definition of four types of reflection and to practice each type of reflection by responding to guiding questions and completing reflection papers (Visscher-Voerman & Procee, 2007). Among the four types of reflection, circle reflection particularly directs students to reflect on their role in society and their professional identity. In a word, there has been considerable effort in developing various strategies to stimulate different aspects of reflection for designers, particularly novice designers.

Because design problems are ill-structured and complicated, during the process of solving design problems, designers may reflect at different times, on different things, and at different levels. With divergent backgrounds and various levels of design expertise, designers may have distinctive reflection patterns that differ from those of other designers. To identify strategies that will promote designers' reflection and ultimately improve their design performance, it is necessary for educators and researchers to understand designers' original reflective behaviors and the association between their reflection and their design performance.

Purpose of the Study

In the current literature in the design field, there are previous studies that examine designers' reflection processes (e.g., Schön, 1987). Some studies reported that reflection behaviors were observed in the design processes (e.g., Greeno et al, 1990; Lloyd & Scott, 1994). There are also studies that were carried out to investigate when designers engaged in reflection and how the timing of their reflection influenced their design performance. Valkenburg and Dorst (1998) found that designers who began to reflect toward the end of the design process achieved a lower performance than the designers who engaged in a balanced frequency of reflection throughout the entire design process. Adams and her colleagues' (2003) research in the context of engineering design also suggests that reflection occurring during more design stages would help students develop high-quality artifacts. These existing studies suggest that different reflection profiles can lead to different levels of design performance. When identifying strategies, educators and researchers should consider how each aspect of reflection would influence the designers' performance. Building upon this concept, we argue that there is also a need to examine the objects that designers reflect upon, the levels of designers' reflection, and how these different aspects of reflection influence designers' performance in design. Accordingly, the goal of the present study is to investigate the reflection patterns of novice designers and to explore the relationship between each aspect of their reflection and their level of design performance. To achieve this goal, three research questions are formed to guide this study:

1. What are novice designers' reflection patterns?

2. What is the relationship between novice designers' reflection patterns and their performance?

3. What are the differences in the reflection patterns between high and low performing novice designers when completing the given design task?

In the following section, the theoretical model is introduced to guide the inquiry into novice designers' reflection in solving design problems.

Three-Dimensional Model of Reflective Thinking in Solving Design Problems

Reflective thinking has been discussed by numerous scholars with regard to developing one's professionalism (e.g., Dewey, 1933; Schön, 1987; Mezirow, 1990), improving students' learning experience (e.g., Boud, Keogh, & Walker, 1985; Lin, Hmelo, Kinzer, & Secules, 1999), and advancing designers' ability in performing design tasks. In the context of solving design problems, reflective thinking is regarded as conscious mental activities that examine designers' courses of action, decisions, and their inner selves in given situations throughout a design process. With their introspective contemplation on various issues, designers actively derive new thinking and make changes to improve unsatisfactory situations. All of the designers' deliberate efforts to change their thinking and ways of interpreting the world, both on individual and societal levels, are considered to be acts of reflective thinking. To comprehensively capture designers' reflective thinking, Hong and Choi (in press) developed a three-dimensional model based on the existing literature in the fields of design and reflective thinking (shown in Figure 4.1). These three dimensions are the timing of reflection, the objects of reflection, and the levels of reflection.

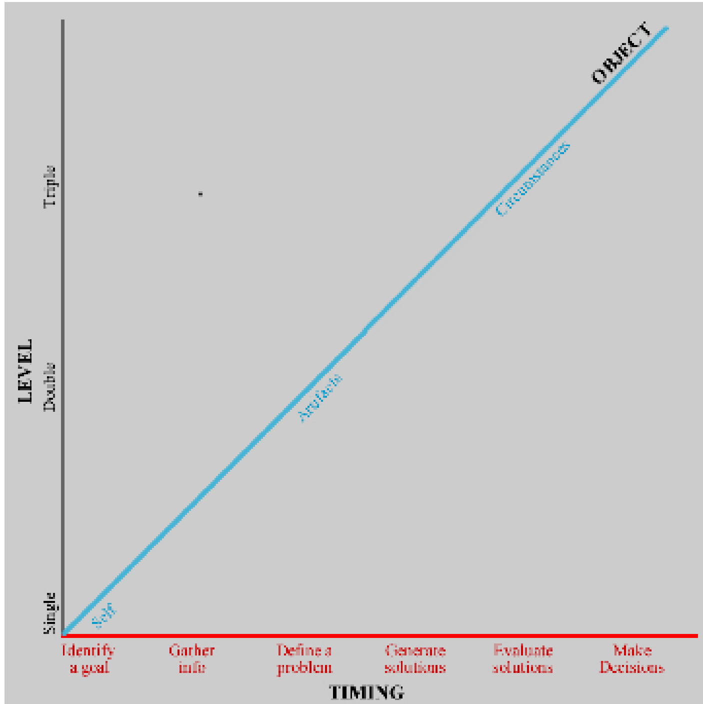


Figure 4.1. A framework for capturing designers' reflective thinking.

Dimension I: Timing of Reflection

Designers' reflection can occur at any time during a design process. Dimension I examines the timing when designers are thinking reflectively. A good design is the result of several cycles of iterations during a design process (Adams et al., 2003). In a study conducted to understand the design processes of senior and freshman engineering students, more iterative behaviors were found in the design processes of the seniors than those of the freshmen (Atman, Cardella, Turns, & Adams, 2005). Senior students frequently shifted among different design stages throughout the entire design process, while freshman students spent large chunks of time in each design stage. Moreover, senior students moved around among more different design stages than freshman students did. The transitions were the results of their reflection (Adams et al., 2003). Another study shows that a design team that began to reflect at an early stage and continued to reflect throughout the design processes performed better than a design team that reflected only more heavily toward the end of the design process (Valkenburg & Dorst, 1998).

These studies have shown that the timing of reflection may influence the quality of the final design. Therefore, the examination of when designers exercise their reflection helps us understand designers' reflection. To explore when designers engage in reflection, two methods are identified in Dimension I. One method is to examine the time period during which designers exercise reflection, and the other is to inspect the design stage in which reflection occurs. To examine the design stages in which reflection occurs, an inquiry of the literature across design disciplines, including instructional design (Dick, Carey, & Carey, 2009), architectural design (Darke, 1979; Maver, 1970; Robinson, 1986), and engineering design (Cross, 2000; Eide, Jenison, Mashaw, & Northup, 2002), has resulted in the creation of six design stages: (1) identifying a goal, (2) gathering information, (3) defining a problem, (4) generating solutions, (5) evaluating solutions, and (6) making a decision.

Dimension II: Objects of Reflection

Since solving design problems is a large, complex, and ill-defined task, designers' reflective thinking can be complicated. Accordingly, the objects that designers reflect upon each time vary. As Visscher-Voerman and Procee (2007) assert, "the concept of reflection is vague, meaning different things for different persons, and students have difficulty in doing it" (p. 344). To make the reflective thinking situated in the context of performing design tasks more concrete, three different types of objects upon which designers reflect are identified: self, artifacts, and circumstances (see Figure 4.2).

Reflection upon Self

A design process is illustrated as a dialogue that "occurs through the designers' perception of the sketched concepts, reflection on the ideas that they represent, and their implications for the resolution of the problem" (Cross, 2000, p.20). When performing design

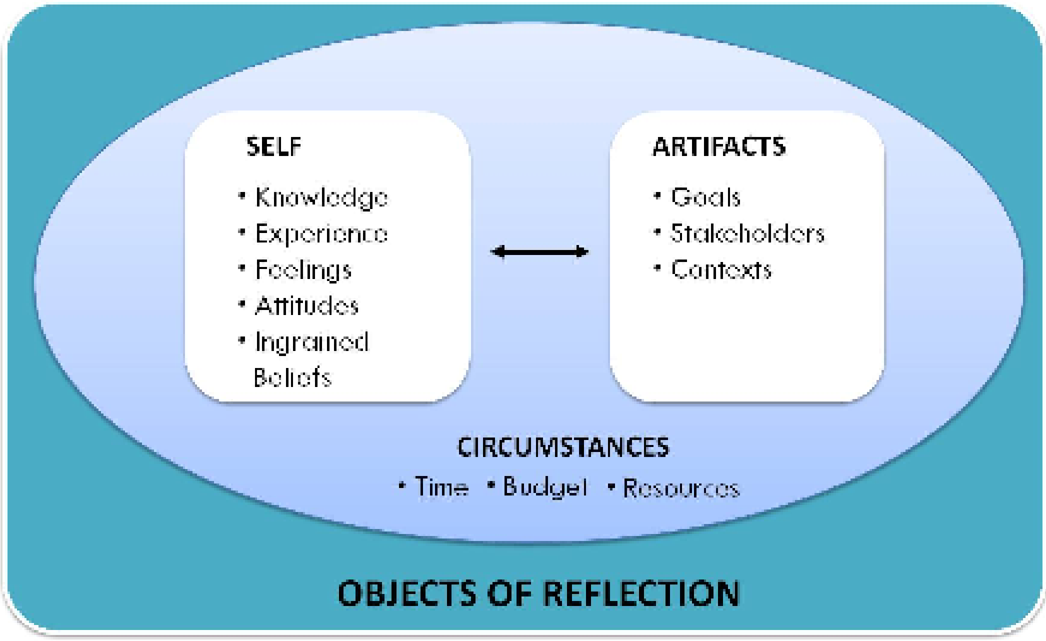


Figure 4. 2. Dimension II: objects of reflective thinking.

tasks, designers themselves play a significant role. Thus, they should always reflect upon themselves in light of their own knowledge, experience, feelings, attitudes, and ingrained beliefs and values during their design processes. First, designers may reflect upon their own knowledge. When solving design problems, it is difficult for designers to equip themselves with all the necessary knowledge and to appropriately apply this knowledge to the problematic situations (Dewey, 1933). Furthermore, designers should be able to organize a wealth of related knowledge (Kavakli & Gero, 2002). By doing so, the knowledge can easily be located when needed. As for designers' experience, designers are inclined to rely on their past design experience to perform the design task (Ahmed, Wallace, & Blessing, 2003; Marsh, 1997). By reflecting upon their previous experience, experts are more likely to question the obtained information, be aware of how a given issue affects another issue, and be able to recognize the limitations that may arise in the later stage of the design (Ahmed, Wallace, & Blessing, 2003; Christiaans & Dorst, 1992). In addition, during a design process, designers often experience changing feelings such as surprise, confusion, and disappointment (Boud, Keogh, & Walker, 1985; Schön, 1983). When consciously attending to their own feelings, designers may reflect upon the change in their feelings in relation to the design process (Dewey, 1933; Schön, 1983). The fourth factor that designers may reflect upon when solving design problems is their attitudes. Dewey (1933) asserted that simply reflecting on knowledge does not suffice to improve the practice. To achieve a good outcome, designers should reflect on whether or not they are open-minded, responsible, and whole-hearted when dealing with the task. Thus, examining designers' attitudes should be carefully considered to ensure designers' persistence. The last factor that designers may consciously examine is their ingrained beliefs and values. Reflection not only enables designers to correct errors in their knowledge or problem-solving processes but also allows them to examine and challenge the presuppositions that have been developed through their upbringing (Mezirow, 1990). By reflecting upon their long-held beliefs, designers may open up opportunities to embrace divergent perspectives. Accordingly, the new understanding and alternatives will emerge to give designers capacity to come up with an artifact that will benefit the larger population and people from all backgrounds.

Reflection upon Artifacts

Design processes are comprised of interdependent and complex relationships among designers, artifacts, users, and contexts. Maier and Fadel (2009) stated that "artifacts are always designed for human use, usually designed by human themselves and situated within a larger context of a complex world economy" (p.18). Thus, it is essential for designers to reflect upon aspects related to artifacts, including the goal or the function of an artifact, stakeholders, and contexts. The first and foremost responsibility as a designer is to design a product or a system that satisfies its functional requirements (Jonassen, 2008; Mostow, 1985). During a design process, designers continuously search for the goals or the functions of the product to improve a problematic situation. As people's needs are not given directly to designers (Norman, 2004), designers should reflect on and examine the interplay of human needs, constraints, and criteria so that the desired functions of an artifact will accordingly emerge. Second, designers need to reflect upon stakeholders. A good design is unlikely to be achieved without thinking of stakeholders. The features of a design are influenced by stakeholders' needs, preferences, and their willingness to compromise (Krick, 1969). In addition, designers should also take into consideration the end users' needs. To avoid designing like novices, designers should assimilate the end users' perspectives (Newstetter & McCracken, 2001). Another aspect that designers should take into account regarding the artifact type is the context in which a product is operated. A product often closely interacts with the contextual factors in its environment. Norman (1996) pointed out that in design, cultural, social, and organizational factors dominate designers' decisions. Moreover, the economic and political impacts on design actions should likewise be considered (Asimow, 1962; Krick, 1969; Norman, 1988). Thus, designers should attend to the effects of contextual factors on their design. Simultaneously, they need to pay equal attention to how the result of design tasks affects the society.

Reflection upon Circumstances

When solving design problems, different circumstances are likely to yield different design outcomes. Circumstances are referred to as the conditions under which a design task is performed. In the existing literature, limited effort has been made to direct designers' attention to considering the circumstances around a design task. In real design practice, these circumstances are often seen as constraints for a given design task such as available budget, time, and resources as well as the politics within an organization (Eide et al., 2002; Jonassen, 2008; Kenny, Zhang, Schwier, & Campbell, 2005). Several scholars pointed out that in the design practice, design activities are often entangled with project management issues (e.g., creating a budget and tracking progress) (Eide et al., 2002; Kenny et al., 2005). Jonassen (2008) similarly argued that designers need to keep a close eye on available technologies, funds, talent, and politics in an organization when performing design tasks. Also, designers should evaluate how these circumstances affect the development and production stage because a good design can help minimize the time and cost needed for development (Fynes & Burca, 2005). All told, these studies inform designers of the importance of reflecting upon how these circumstances influence a design process.

Dimension III: Levels of Reflection

The third dimension for examining designers' reflection is to investigate the levels of their reflective thinking (Kember, 2000; Mezirow, 1990). The investigation of designers' levels of reflection adopts Argyris and Schön's idea of single-loop and double-loop learning (1978) as well as Flood and Romm's triple-loop learning (1996). Single-loop reflective thinking can be described as a trouble-shooting experience. Flood and Romm (1996) argued that designers who reflect on the single-loop level adopt means-end thinking. These designers often have a clear and fixed goal to reach. During the design process, they may experience technical problems or have difficulties generating a solution that aligns with the defined goal. With single-loop reflective thinking, designers examine and explore possible actions or solutions based on the criteria of efficiency and effectiveness to correct the errors so as to achieve the already-defined goal (Argyris & Schön, 1978; Usher & Bryant, 1989). In some situations, designers may find it necessary to take a further step to reflect on a deeper level. A better design may require designers to employ double-loop reflective thinking. With double-loop reflective thinking, designers question and examine the goals, criteria, functions, and constraints to redefine the problems

(Flood & Romm, 1996; Mason, 2008; Van Manen, 1977). After examining their assumptions about how they define the problems, designers revisit the previous solutions to ensure that the solutions address the redefined goal. In addition to single-loop and double-loop reflective thinking, some designers also reflect on the triple-loop level. Such designers take into account broader aspects such as cultural, economic, historical, and political influences on a design process or a decision. Triple-loop reflective thinking is also labeled as critical reflection (Mezirow, 1990; Moallem, 1998; Van Manen, 1977). Designers question their design processes as to how the dominant culture influences their decisions when solving design problems (Moallem, 1998). Thus, with triple-loop reflection, designers will be able to reach out beyond their own frame of thinking so that their design may result in a large-scale transformation of the entire society. These three levels of reflection allow us to gain a more holistic understanding of designers' reflection and further to examine the relationship between the depth of designers' reflection and their design performance.

Methods

Research Context and Design Project

The data were collected from a course titled as an Introduction to Micro- and Nano-Biotechnology. The course was three credit hours and was offered in the Department of Bioengineering at a large public university on the West Coast in the United States. To enroll in the course, students were required to complete the following prerequisites: two physics courses and one chemistry course. The primary objectives for these courses are: (1) to build a basic foundation for understanding the mechanisms of electrical, mechanical, chemical, and optical transducers in the context of biomedical applications, (2) to teach critical thinking in nano- and micro-engineering design issues, (3) to review current medical devices along with the examination of the viability of nano-scale devices and biomedical microelectromechanical systems technology in a particular biomedical application, and (4) to teach practical designs of nano- and micro-scale medical devices. The course met twice a week for ninety minutes each session. In addition, the discussion sessions were offered two hours a week for students to discuss the design projects with the instructor and to solicit help with homework assignments from the teaching assistant. Students enrolled in this course were required to complete a team design project. At the beginning of the semester, students were asked to form a team with a group of three to five members. It was recommended that the composition of the team member consists of students from different backgrounds, such as physics, chemistry, mechanical engineering, and bioengineering. After forming the group, students reviewed the related literature and selected a topic of their common interest. An example topic of a team project was to design an innovative device for rapid melanoma diagnosis. In total, students had 14 weeks to complete the projects and most team discussions took place outside of the scheduled class time. At the end of the semester, each team was required to present their design concept to the class. The primary selection criterion of this research site for our study is that the students were required to perform an open-ended ill-structured design project. The instructor did not provide a specific area or a topic for the design project. Instead, students were asked to identify a biomedical device or a system currently used that needs further improvement. The design of the given project provided students with an opportunity to experience real-world problems in a more natural setting.

Participants

The participants were 44 students enrolled in the Introduction to Micro- and Nano-Biotechnology course. The average age of the participants was 21.61 years, and 68% were male.

36 participants were undergraduate students, and a majority of them were juniors (n=12) and seniors (n=22). There were also five graduate students who were in the first year of their graduate programs. As for their experience in design, more than half of participants (n=23) indicated that they had never performed a design project before; 18 participants had one to three years of experience in design; one had three to five years of experience; and one had more than ten years of experience. Even though the majority of participants were majoring in bioengineering, there were five participants from other majors such as mechanical engineering, electrical engineering, and chemistry. Most participants indicated that they did not have experience in designing a biomedical device or system before taking this course.

Instrument for Eliciting Reflection Behaviors

To capture participants' reflection patterns, a newly developed questionnaire, titled "Reflective Thinking in Solving Design Problems (RTSDP)," was employed (Hong & Choi, in preparation). The questionnaire is composed of three sections: (1) the timing of reflection, (2) the objects of reflection, and (3) the levels of reflection. The original RTSDP questionnaire consists of 42 items. Two rounds of data were collected to examine the validity and reliability of the questionnaire. As examination of the items in the RTSDP questionnaire has not been concluded, participants in this study were provided with the full length of the RTSDP questionnaire (See Appendix 4.A). The following investigation of participants' reflection patterns was conducted by selecting the items that have reached an acceptable level of reliability and validity. The reliability was examined by calculating the Pearson's correlation coefficients and Cronbach's alphas. The validity tests were examined by performing exploratory factor analyses. The RTSDP questionnaire with the items that were used for this study is shown in Appendix 4.B.

Dimension I: Timing of Reflection

In the first section of the RTSDP questionnaire, two items were used to examine the timing of the participants' reflection. Participants were asked to rate the frequency of their reflection occurring during each of three time periods (i.e., week four – week seven, week eight-week eleven, week twelve – week sixteen) and at each design stage (i.e., identifying a goal, gathering information, defining a problem, generating solutions, evaluating solutions, and making decisions). These two items were verified by test-retest reliability using the Pearson's correlation coefficients in the previous validation study (Hong & Choi, in preparation). The participants of the previous study were asked to rate the frequency of their reflection for each design stage and each time period immediately after they concluded the design task. Two weeks later they were asked to rate the same items again. The correlation coefficients for each design step between the first test and the second test ranged from .332 to .592. Two design steps (i.e., identifying a goal and defining a problem) achieved a moderate level of reliability and the positive correlations between the test and the retest for these two design steps were significant at the 0.05 level. The correlations for the other four design steps (i.e., gathering information, generating solutions, evaluation solutions, and making decisions) reached a strong level of reliability. The positive correlations between the two tests were significant at the 0.01 level. For the items that examine participants' frequency of reflection for each time period, the correlation coefficients for each of the three design periods between the two tests were .531 (period one), .505 (period two), and .696 (period three). A strong level of correlation for all three time periods was observed. According to the correlation coefficient result, the two items in this dimension were concluded to be able to reliably measure the times that designers engage in reflection. A ten-point scale from zero (Never) to ten (Constantly) was provided.

Dimension II: Objects of Reflection

Based on the results of the validity and reliability tests, 21 items were selected to examine how frequently the participants reflected upon the identified objects. The 21 items are categorized into three factors, including reflection upon self (11 items), reflection upon artifacts (six items), and reflection upon circumstances (four items). Under the factor of reflection upon self, five sub-factors were identified, including knowledge, experience, feelings, attitudes, and ingrained beliefs and values. The Cronbach's alpha values were calculated for each of the five factors, ranging from .57 to .84. The overall Cronbach's alpha value for the 11 items under the factor of self indicated a satisfactory internal consistency (α =.82). For the reflection upon artifacts factor, three sub-factors were recognized: goals, stakeholders, and contexts. Two items were retained for each sub-factor. The Cronbach's alpha values for the three sub-factors were .56 (goals), .59 (stakeholders), and .49 (contexts). The overall Cronbach's alpha value was .68. The last factor in dimension two is reflection upon circumstances. No sub-factor was identified, and four items were developed. A slightly low Cronbach's alpha value (α =.40) was obtained. Even though the data collected in this study demonstrated a low internal consistency among these four items, the previous validation study concluded an acceptable level of internal consistency (α =.66). The four aspects summarized from the existing literature for this factor were reflection on budget allocation, equipment resources management, human resources management, and time management. Owing to the nature of the class design project, participants were more inclined to reflect on time management than on other aspects (i.e., budget, equipment resources, and human resources). Even though a low internal consistency was obtained, with the acceptable level of the internal consistency from our previous validation study and the particular phenomena of a class project, these four items could legitimately be retained for discovering participants' reflection on the circumstances of the design task. The 21 items used to examine designers' reflection on objects were evaluated with a five-point scale, ranging from zero (never) to four (always).

Dimension III: Levels of Reflection

The last section allowed participants to self-evaluate the level of reflection they achieved. Three levels of reflection were identified: single-loop reflective thinking, double-loop reflective thinking, and triple-loop reflective thinking. In total, 11 items were retained. The Cronbach's alpha values demonstrated strong levels of internal consistency for each level: the single-loop level (α =.75), the double-loop level (α =.72), and the triple-loop level (α =.90). The overall alpha for the 11 items was .88. To assess participants' level of reflection, a five-point scale, ranging from zero (never) to four (always) was employed.

Evaluating Design Performance

The participants' design performance was collected from the instructor's evaluation on participants' individual reports. Toward the conclusion of the project, each participant was required to write an individual report using the design concept generated by their team. Each student took one of the perspectives of their team design concept to compose the report. The instructor evaluated the individual reports based on the following criteria: originality, fundamental logic, experimental design, presentation of the design concept, literature review of related areas, and clarity of writing. As the given project was a team project, the instructor also considered each participant's contribution to the generation of their team design concept when assigning grades. The instructor observed each student's contribution through participants' interaction with their teammates in regular meetings, their responses to the evaluation of individual contribution to their teams, and their design journals. The full score of the individual report was 100. Based on the scores of the individual reports, 44 participants were categorized into three groups. 15 participants who received the scores of 80 and 85 were categorized as the low performers; 13 participants who received the scores of 87and 90 were classified as the middle performers; and 16 participants who obtained the scores of 95 and 97 were regarded as the high performers. The categorization of participants' performance levels was later used to compare the differences in the reflection patterns of high and low performing participants.

Data Collection

The data collection for this study consists of two elements: (1) the participants' responses to the RTSDP questionnaire and (2) the instructor's evaluations of participants' individual reports. At the conclusion of the team project, two sessions were scheduled for the participants to present the team design concept to the class. At the end of the second presentation session, the participants were asked to respond to the paper-based RTSDP questionnaire during the class. Participants' responses to the RTSDP questionnaire were retrospective evaluations of their reflective patterns when completing their design project and were based on their own perception. After all participants finished team presentations, they were provided with a link and login information to the Comprehensive Assessment for Team-Members Effectiveness (CATME) website to evaluate their team members' contributions (Loughry, Ohland, & Moore, 2007). One week after their presentations, participants were required to submit individual reports to the instructor. The instructor used participants' individual final reports and their response to the CATME peer contribution evaluation questionnaire to assign grades. After completing grading of participants' individual reports, the instructor provided the participants' scores to the researchers.

Data Analysis Procedures

The data were analyzed according to three research questions: (1) the perceived reflection patterns of novice designers, (2) the relationship between novices' self-reported reflection patterns and their design performance, and (3) the comparison of self-reported reflection patterns between low and high performing novices. The novice designers' perceived reflection patterns were analyzed using descriptive statistics. Pearson's correlation coefficients were computed to explore the relationship between novices' self-reported reflection patterns and their performance. For the last research question, one-way ANOVA analyses were performed to obtain the comparison of self-reported reflection patterns between the high- and low-performing groups of novice designers. The summary of the research questions and the corresponding data analysis methods are presented in Table 4.1.

Table 4.1
Summary of Research Questions and Data Analysis Methods

Research Question	Statistical Method
1.What are novice designers' perceived reflection patterns? (1) When do they reflect more frequently during a design process? (2) What objects do they reflect upon? (3) What levels of reflection do they achieve?	• Descriptive statistics
2.What is the relationship between novice designers' self-reported reflection patterns and their design performance? (1) timing of reflection vs. design performance (2) objects of reflection vs. design performance (3) levels of reflection vs. design performance	• Pearson's correlation coefficients
3.What are the differences in the self-reported reflection patterns between high and low performing novice designers when completing the given design task? (1) timing of reflection (2) objects of reflection (3) levels of reflection	• One-way ANOVA analyses

Results

Novice Designers' Self-Reported Reflection Patterns

To examine novice designers' timing of reflection, participants' responses regarding their reflection occurring at each design stage and during each time period were utilized. The means and standard deviations for all design stages and all design periods are presented in Table 4.2.

Table 4.2
Reflection Patterns and Performance in Solving Design Problems

	Total (*N=44*) Mean (SD)	Low (*n=15*) Mean (SD)	High (*n=16*) Mean (SD)	F	P	Correlation+
Timing (Design Stage)						
Identify a goal	7.52 (1.96)	6.40 (2.38)	8.25 (1.39)	7.076 (1, 29)	.013*	.398**
Gather information	8.50 (1.46)	8.07 (1.79)	9.06 (.93)	3.847 (1, 29)	.059	.292
Define a problem	7.23 (1.51)	7.00 (1.31)	7.63 (1.67)	1.334 (1, 29)	.258	.178
Generate solutions	7.56 (1.44)	6.87 (1.77)	8.19 (.83)	7.231 (1, 29)	.012*	.395**
Evaluate solutions	7.70 (1.71)	6.93 (2.19)	8.13 (1.20)	3.595 (1, 29)	.068	.294
Make decision	7.41 (1.93)	7.07 (1.75)	8.31 (1.30)	5.097 (1, 29)	.032*	.278
Timing (Design Period)						
Period 1 (Week 4-7)	5.73 (2.00)	4.80 (2.08)	6.44 (1.75)	5.661 (1, 29)	.024*	.346*
Period 2 (Week 8-11)	6.68 (1.61)	6.13 (1.46)	7.19 (1.60)	3.660 (1, 29)	.066	.278
Period 3 (Week 12-16)	8.68 (1.25)	7.93 (1.39)	9.00 (.89)	6.561 (1, 29)	.016*	.357*
Object						
Self_Knowledge	4.12 (.64)	3.97 (.69)	4.38 (.43)	3.947 (1, 29)	.056	.273
Self_Experience	3.55 (1.04)	3.50 (1.07)	3.75 (.91)	.492 (1, 29)	.488	.104
Self_Feelings	3.30 (1.00)	2.80 (.69)	3.42 (1.04)	3.719 (1, 29)	.064	.254
Self_Attitudes	4.06 (.78)	3.53 (.58)	4.31 (.66)	12.202 (1, 29)	.002**	.422**
Self_Beliefs	2.68 (1.25)	1.77 (.84)	3.19 (1.26)	13.382 (1, 29)	.001**	.479**
Artifact_Goals	3.86 (.67)	3.50 (.76)	3.91 (.49)	3.192 (1, 29)	.084	.252
Artifact_Stakeholders	4.03 (.83)	3.90 (.74)	4.19 (.63)	1.371 (1, 29)	.251	.147
Artifact_Contexts	3.47 (.77)	3.07 (.80)	3.66 (.44)	6.618 (1, 29)	.015*	.323*
Circumstance	3.27 (.61)	2.95 (.41)	3.48 (.38)	13.987 (1, 29)	.001**	.368*
Level						
Single	4.10 (.64)	3.82 (.70)	4.19 (.58)	2.574 (1,29)	.119	.243
Double	3.67 (.68)	3.36 (.58)	3.73 (.71)	2.533 (1,29)	.122	.229
Triple	2.40 (1.21)	2.18 (1.17)	2.53 (1.03)	.773 (1,29)	.387	.121

** Denotes a correlation that is significant at the 0.01 level
* Denotes a correlation that is significant at the 0.05 level
+ Correlation between each reflection aspect and the performance in design project

Among identified design stages, gathering information (*M* = 8.50, *SD* = 1.46), evaluating solutions (*M* = 7.70, *SD* = 1.71), and generating solutions (*M* =7.56, *SD* = 1.44) were the three stages when participants reported that they reflected the most frequently. For the reflection during the three design periods, participants reported that their reflection occurred the least frequently at the beginning of the design process (*M* = 5.73, *SD* = 2.00). The frequency of their reflection increased as they moved toward the end of the design (*M* = 8.68, *SD* = 1.25).

With regard to the objects that participants reflected upon, participants expressed that they always reflected on their own knowledge (*M* = 4.12, *SD* = 0.64), attitudes (*M* = 4.06, *SD* = 0.78), and the stakeholders of the design project (*M* = 4.03, *SD* = 0.83). On the other hand, they seldom reflected on their ingrained beliefs and personal values when performing the design task (*M* = 2.68, *SD* = 1.25). In Table 4.2, the means and standard deviations for participants' frequency of reflection on each object are presented.

Based on participants' self-evaluation of their levels of reflection, when performing the given design task, participants indicated that they always reflected at the single-loop reflective thinking (*M* = 4.10, *SD* = .64), sometimes reflected at the double-loop reflection (*M* = 3.67, *SD* = .68), and seldom reflected at the triple-loop reflection level (*M* = 2.40, *SD* = 1.21) as shown in Table 4.2.

The Relationship Between Novice Designers' Self-Reported Reflection Patterns and Their Design Performance

Pearson's correlation coefficients were used to investigate the relationship between each aspect of participants' self-reported reflection and their design performance (See Table 4.2). For the timing of reflection, a high frequency of reflection taking place at two design stages (i.e., identifying the goal and generating solutions) was significantly correlated with high design performance. For the reflection occurring during each design period, there are positive correlations between participants' design performance and their reflection at the beginning and toward the end of the design process. Regarding the relationship between the frequency of reflection on each identified object and design performance, participants who indicated that they reflected more on their attitudes, their ingrained beliefs and values, the contexts of the artifacts being used, and the circumstances of the design task obtained higher design performance scores. For the relationship between participants' different levels of reflection and their performance in design, no strong correlation was observed.

The Difference in Self-Reported Reflection Patterns between High and Low Performers in Solving Design Problems

One-way ANOVA analyses were utilized to discover the distinctive reflection patterns self-rated between low and high performing participants (See Table 4.2). For the participants' perceived reflection taking place at six design stages, significant differences in the frequency of reflection occurring when identifying a goal [F (1, 29) = 7.076, p = .013], generating solutions [F (1, 29) = 7.231, p = .012], and making decisions [F (1, 29) = 5.097, p = .032] between the two groups were detected. The participants in the high performing group reportedly reflected more frequently when identifying a goal (M = 8.25, SD = 1.39), generating solutions (M = 8.19, SD

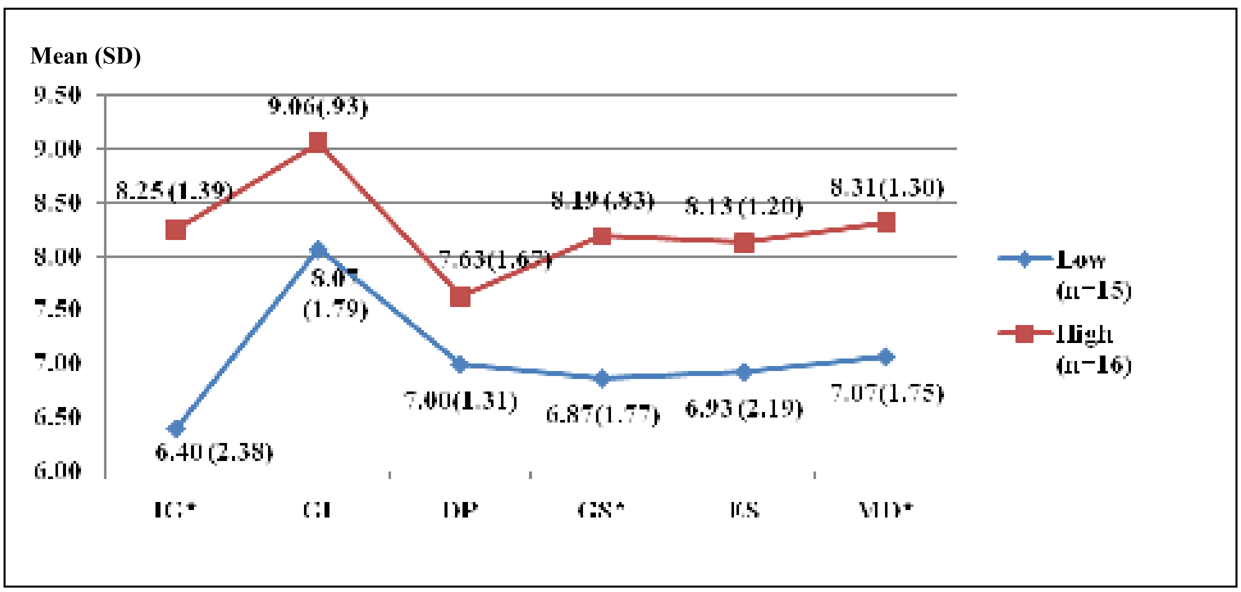


Figure 4.3. High and low performers' perceived frequency of reflection at each design stage.
Notes: IG = Identify a goal; GI = Gather information; DP = Define the problem; GS = Generate solutions; ES = Evaluate solutions; MD = Making decisions; * Denotes the design stage that has significant difference between groups

= .83), and making decisions (M = 8.31, SD = 1.30) than the participants in the low performing group did when identifying a goal (M = 6.40, SD = 2.38), generating solutions (M = 6.87, SD = 1.77), and making decisions (M = 7.07, SD = 1.75) respectively. Figure 4.3 illustrates the average scores of the perceived frequency of reflection at different design stages for low and high performers.

For the frequency of reflection occurring during the three design periods, a significant difference in the frequency of reflection between two groups was obtained for period one, F (1, 29) = 5.661, p = .024, and period three, F (1, 29) = 6.561, p = .016. The high performing participants reportedly engaged in more reflection at the beginning of the design process (period one, M = 6.44, SD = 1.75) than the low performing participants did in the same period one (M = 4.80, SD = 2.08). During the last period of design process, the high performing participations (M = 9.00, SD = 0.89) also reportedly engaged in more reflection than the low performing

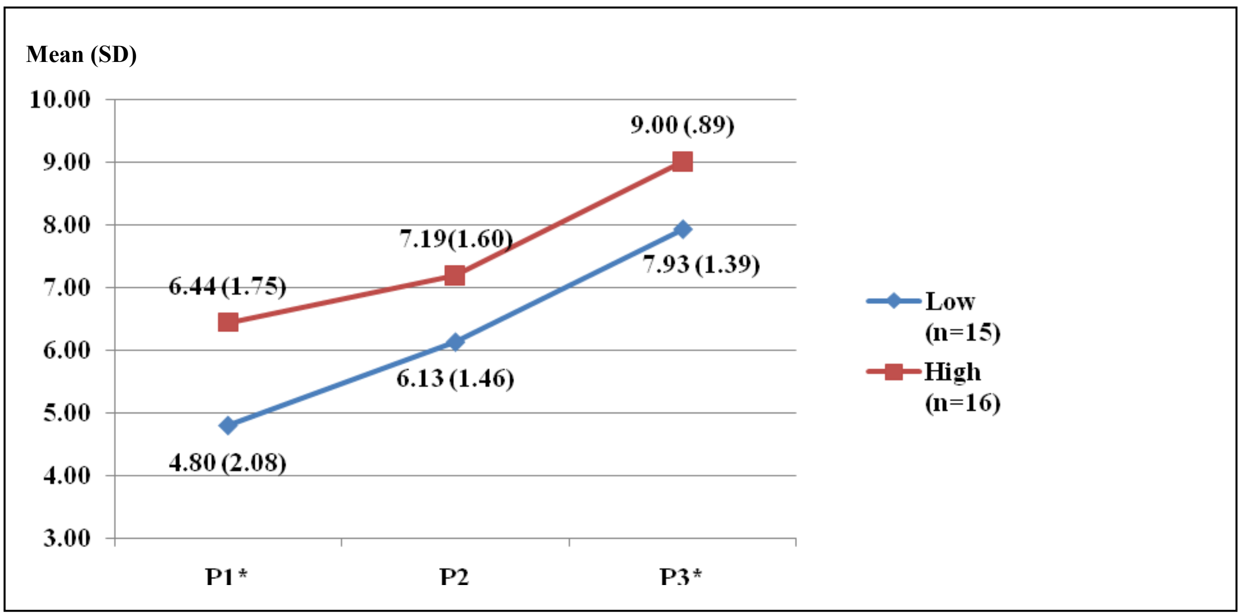


Figure 4.4. High and low performers' perceived frequency of reflection during each design period.

Notes: P1 = Period 1 (Week 4 – Week 7); P2 = Period 2 (Week 8 – Week 11); P3 = Period 3 (Week 12 – Week 16); * Denotes the design stage that has significant difference between groups participants did (M = 7.93, SD = 1.39). In Figure 4.4, the high performers' and the low performers' self-rated frequency of reflection during each design period is presented. Comparing participants' self-assessed frequency of reflection on identified objects, the two groups demonstrated significantly different frequency of reflection on the following four objects: reflection on their attitudes [F (1, 29) = 12.202, p = .002], their ingrained beliefs and values [F (1, 29) = 13.382, p = .001], the contexts of artifacts being operated [F (1, 29) = 6.618, p = .015], and the circumstances of the given design task [F (1, 29) = 13.987, p = .001]. The participants in the high performing group reportedly reflected more frequently on their attitudes (M = 4.31, SD = .66), their ingrained beliefs and values (M = 3.19, SD = 1.26), the contexts of using artifacts (M = 3.66, SD = .44), and the circumstances of the given design tasks (M =3.48, SD = .38) than their counterparts did on their attitudes (M = 3.53, SD = .58), their ingrained beliefs and values (M = 1.77, SD = .84), the contexts of operating artifacts (M = 3.07, SD = .80), and the circumstantial

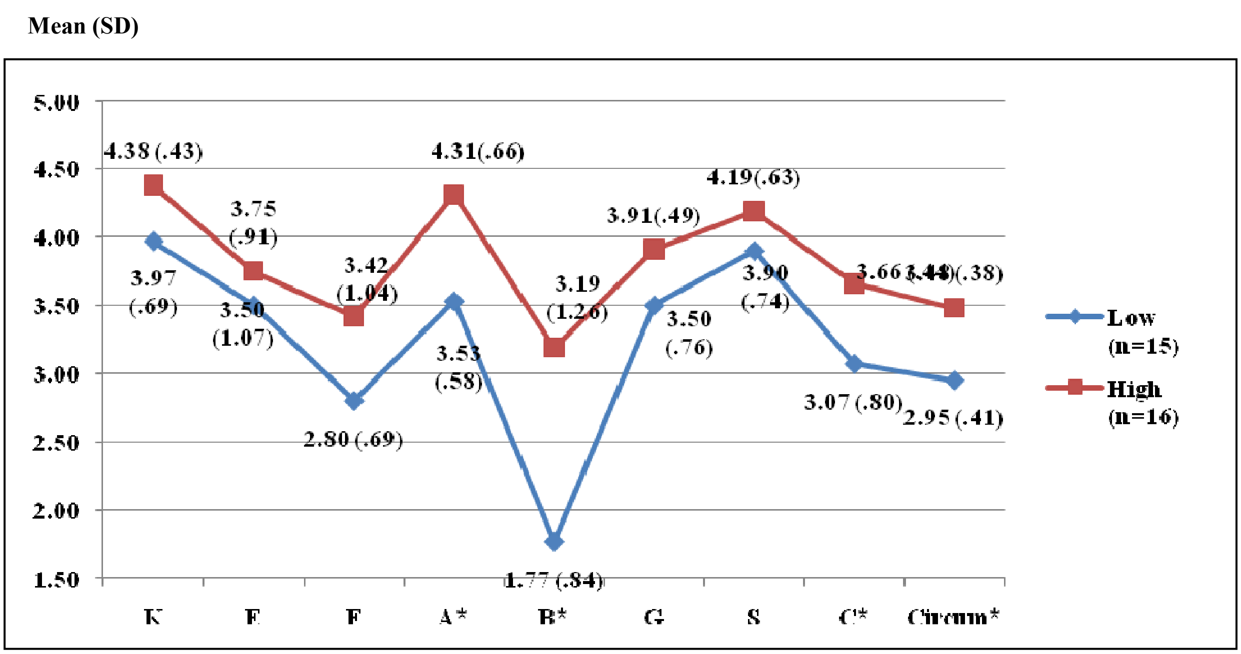


Figure 4.5. High and low performers' perceived frequency of reflection on each object.
Notes: K = Knowledge; E = Experience; F = Feeling; A = Attitude; B = Ingrained beliefs and values; G = Goal; S = Stakeholder; C = Context; Circum = Circumstances; * Denotes the design stage that has significant difference between groups

issues of the given design task (*M* = 2.95, *SD* = .41). Figure 4.5 shows participants' perceived frequency of reflection on each object for both high and low performers.

Dissimilar to the first two dimensions, the perceived frequency of reflection for the three identified levels of reflection between the two groups did not demonstrate significant difference. Although the result suggests no significant difference in participants' self-reported reflection at three levels, for each of the three levels, high performing participants reportedly reflected slightly more frequent than the low performing participants did. The perceived frequency of reflection for each level between high and low performers is illustrated in Figure 4.6.

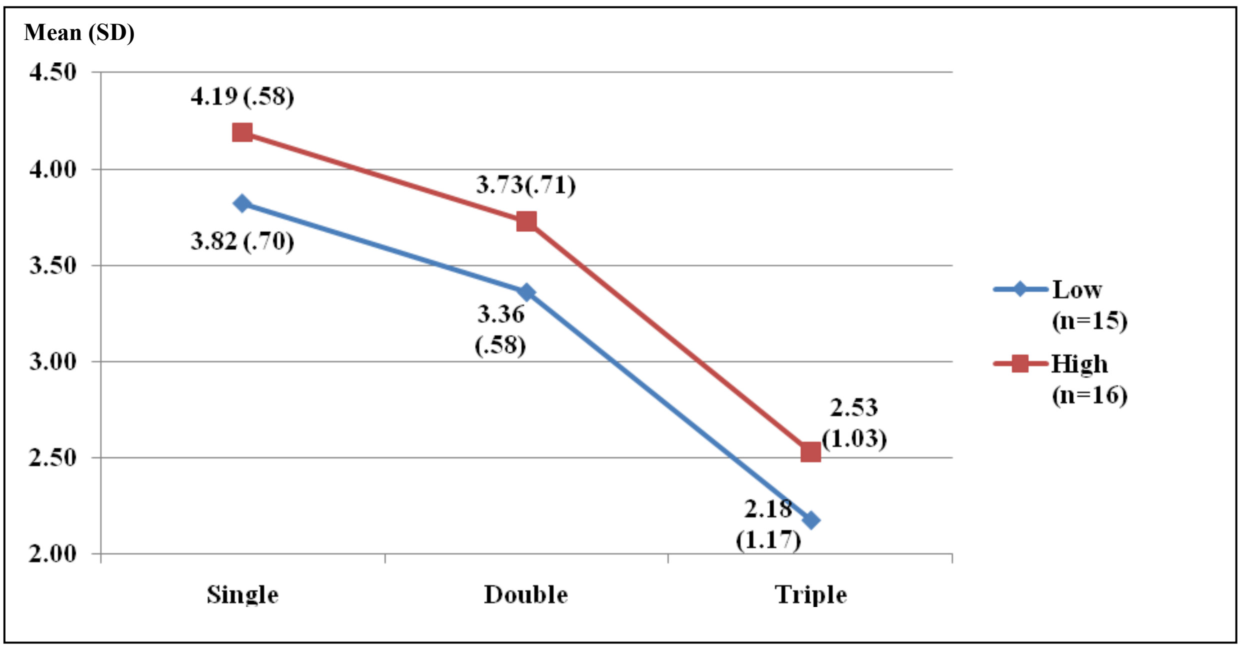


Figure 4.6. High and low performers' perceived frequency of reflection on each level.

Discussions

We investigated novice designers' self-reported patterns of reflection when performing the given design task. Also, the relationship between novices' perceived reflection patterns and their design performance was examined. In this section, we discuss three dimensions (i.e., timing of reflection, objects of reflection, and levels of reflection) separately based on the findings (i.e., the perceived reflection patterns of the novice designers, the relationship between self-reported reflection patterns and performance, and the comparison of the self-reported reflection patterns between high and low performers).

Dimension I: Timing of Reflection

Reflection at Design Stages

Among the six identified design stages, the participants considered novices reportedly reflected more frequently when they were gathering information, evaluating solutions, and generating solutions. The participants from both the low and high performance groups indicated that they reflected the most frequently when gathering information. Even though no significant group difference was observed, participants in the high-performing group on average reflected more frequently than the participants in the low-performing group did. A study conducted by Atman and her colleagues (1999) reveals that senior students gathered significantly more pieces of information than freshmen did. In addition, the amount of information gathered correlates with higher quality design concepts. A follow-up study (Atman et al., 2007) that compares the design processes of expert engineers and senior engineering students shows a similar result. The number of pieces of information and the number of categories of information gathered by the expert engineers are significantly higher than the numbers gathered by the senior engineering students. Based on the findings of these two studies and the result of our investigation, the designers' decisions on gathering more information are driven by their reflection. As the result of their reflection occurring at the gathering information stage, designers realized the need to collect more appropriate information for performing the given task. Ultimately, reflective designers would produce higher quality solutions.

The second and the third highest frequency of reflection reportedly occurred during the participants' design processes when they were generating and evaluating solutions. Furthermore, the self-reported frequency of reflection during the generating solutions stage positively correlates with the performance in design. Likewise, Atman and her colleagues found that among senior engineering students, seniors who came up with more solutions demonstrated better performance than those who generated fewer solutions (Atman et al., 1999). In addition, expert engineers considered more solutions than senior engineering students did (Atman et al, 2007). The observation shows that designers who are more experienced and who create high-quality design take into account more solutions. More alternative solutions are generated when designers reflected upon the quality of the solution they previously proposed. The findings suggest that to increase the quality of design, it is necessary to prompt novice designers to engage in reflection when they generate solutions.

Another critical stage for designers to engage in reflection is when designers are identifying the goal of the given design task. According to the participants' self-report of their reflection behaviors, the frequency of reflection during the goal identification stage for high-performing participants is significantly different from the frequency for low-performing participants. The positive correlation is observed between the frequency of reflection during the goal identification stage and design performance. The ill-structured nature of design problems makes them difficult for designers to solve (Jonassen, 2000; Simon, 1973). In most cases, designers form the goal of the project by exploring different components relevant to the given task. Rowland (1993) found that to understand the problem of the given instructional design task, expert designers interpreted the given situation as ill-defined and inferred much additional information, whereas novices saw the program as well-structured and made few inferences. Thus, reflection plays a critical role in their process of setting the goal of the project. In our study, the design task assigned to the novice designers is extremely ill-structured because the instructor did not specify the kind of device to be designed. Instead, the participants were asked to identify the goal (i.e., the type of device and the scope of the project) based on team members' common interest and their previous experience related to the given task. Thus, it manifested the importance for the participants to reflect upon the conversations among their team members, their understanding of their various strengths and expertise, and the information related to the project and potential device to be designed. To identify a goal, a competent designer needs not only examine but also challenge the given information.

The last design stage, making decisions, is also an important stage to engage novice designers in reflection. From the participants' ratings, high performing participants reflected more significantly than the low performing participants. According to Jonassen (2008), "design is an iterative process of decision making" (p.23). When performing design tasks, designers are necessary to be conscious about the decisions they make so that they will be able to come up with next strategies and moves (Rowland 1993). Based on the findings, to facilitate novice designers' reflection at multiple design stages, educators and researchers may consider providing strategies that specifically focus on prompting novice designers to reflect when they are identifying a goal, gathering information, generating solutions, and making decisions.

Reflection at Design Periods

Throughout the entire design process, designers may yield numerous reflection behaviors at different times. Based on the results of participants' self-reported data, the frequency of participants' reflection increased when they approached the end of the design project. The increasing frequency of their reflection might be the result of the increasing time and effort they invested. The comparison of participants' self-rated frequency of reflection during each design period reveals that the high performing participants reportedly reflected significantly more frequently during period one and period three than the low performing participants did. Furthermore, participants who exercised more reflection at the beginning of their design processes demonstrated a higher level of design performance. Similarly, Valkerburg and Dorst (1994) observed that the team that performed better began to reflect in the early stage of their design. On the other hand, the team that yielded relatively low performance reflected mostly at the end of the project. They further argued that reflection taking place toward the end of the process might be too late for designers to make major changes to their design. Accordingly, the quality of their design is low. As novices are new to the design task, it is likely that they lack information and experience as to the sub-tasks to accomplish, the issues to attend to, and the decisions to make. Thus, it is especially critical to provide guidance to novice designers to begin to reflect at the start of their design processes.

Dimension II: Objects of Reflection

The ill-structured and complex characteristics of design problems require designers to reflect on various aspects and issues when performing a design task. According to the participants' self-assessment of their reflection, the participants reflected the most frequently on their knowledge, their attitudes, and the issues related to the stakeholders of the given design task. Nevertheless, based on the result, more frequent reflection on participants' own knowledge and the issues related to the stakeholders did not yield a higher-quality design. Instead, more frequent reflection on participants' own attitudes, their ingrained beliefs and values, the contexts of the artifacts being used, and the issues related to the circumstances of the given design task helped participants produce a higher quality design. First, participants' reflection on their attitudes is one of the important significant indicators of a successful design. As Dewey (1933) argued, when solving problems, “knowledge of the methods alone will not suffice; there must be the desire, the will to employ them” (p.29). With their constant examination of the levels of their responsibility and commitment to the task, novices were more likely to achieve a higher-level of performance as they were willing and found it necessary to take the challenges and tackle the difficulties they have encountered in a design process. Similar to our finding, Reidsema, Goldsmith, and Mort (2010) examined engineering students’ written reflection and found that students who performed better in reflection writing demonstrated strong responsibility for their own professional development.

Another important object that should be heavily reflected upon during a design process is novices’ ingrained beliefs and values. As Moallem (1998) argued, it is important to guide designers to discover their “beliefs or behaviors which preserve the inadequacies of the current system …” (p. 286). With critical reflection, designers examine their underlying assumptions and values during their design practice. Based on our findings, the more reflection on their beliefs and values the participants engage in, the better design performance the participants could achieve. However, most participants in our study indicated that they seldom reflected on their beliefs and values. A similar result was found in the study that examines the reflective thinking of students who are in health-related disciplines (Kember, 2000). Among different types of reflection they identified, critical reflection was reported as the type of reflection that students rarely engaged in. The reason that reflection upon ingrained beliefs and values rarely happens is that the change of one’s major perspective often requires a longer time (Mezirow, 1990). As reflection upon designers’ own ingrained beliefs and values is not often attended to, the necessity for educators and researchers to facilitate novices to reflect in this aspect become salient.

The third object that is critical in directing novice designers to reflect upon is the context of artifacts being operated. Even though participants did not indicate that they reflected frequently upon this aspect, the participants in the high-performing group reflected more significantly on the context of artifacts than the participants in the low-performing group did. Additionally, there is a positive correlation between participants' frequency of reflection on this aspect and their design performance. As novice designers lack experience in design, they may not attend to the context of artifacts being used. Researchers and educators are necessary to derive strategies to direct novices to reflect on how intended contexts affect the to-be-designed artifacts and how the designed artifacts in turn influence the contexts (Norman 1996).

The last object that is important to guide novice designers to reflect upon is the circumstances of the given design task. According to a study conducted by Cox and Osguthorpe (2003), practicing instructional designers indicated that they spent more than half of their professional time in organizational tasks (e.g., project management and supervising personnel). Considering issues related to cost, time, and resources is important for designers, as these aspects of design may influence the scope of the project (Tessmer & Wedman, 1990). Based on the result of the present study, participants indicated that they exercised moderate frequency of reflection on these circumstances. The quality of their performance in design increased as they frequently considered the issues that are related to the circumstances of the given design task. Therefore, it is important for educators and researchers to provide guidance to novice designers to reflect on various issues related to the circumstances of the assigned design project.

Among the various objects that designers may reflect upon, participants reported that they reflected frequently on their knowledge and the issues related to the stakeholders. However, reflection on these two objects did not help participants to produce a high-quality design. Even though the result indicates that participants' design performance was not influenced by the frequent reflection on their knowledge and their considerations related to the stakeholders, we infer that appropriate guidance on reflecting on these two aspects for novice designers may yield a different result. Solving a design problem is an ill-structured task. It requires designers to integrate knowledge from multiple domains (Goel & Pirolli, 1992; Simon, 1973). In addition, designers need to be able to retrieve and organize the necessary knowledge. Guindon (1990) argued “experts organize their knowledge in terms of functional categories in their domains of expertise, whereas novices organize their knowledge in terms of surface features of the problem” (p.282). Moreover, the designers in his study used both general problem-solving schemas and the specialized software design schemas acquired from their previous design experience. The study suggests that to successfully solve design problems, designers need to not only acquire knowledge from multiple domains, but also develop specialized knowledge schemas from the collected information and retrieve them when the situation demands. Thus, the need to help designers, especially novice designers, to reflect on their knowledge becomes more significant.

The participants of the present study also reported that they reflected frequently on the stakeholders of the design task, but their reflection upon this aspect did not lead them to a high-quality design. When designers perform design tasks, it is central for them to address the needs, preferences, and requirements of different stakeholders (Goel & Pirolli, 1992; Houser & Clausing, 1988; Schön, 1996). The stakeholders of a design project often include users and clients. Norman (1996) emphasized that designers should take the challenge of understanding end users’ unmet and unarticulated needs. In many cases, end users may not be fully aware of their true needs, let alone articulate their needs to designers. Thus, designers should assume the responsibility to identify all stakeholders’ perspectives and inquire into their concerns. In our study, even though participants indicated that they took into account end users’ needs and preferences, they did not have chance to interact closely with their end users. Consequently, they were not able to produce a promising design. Based on our observations of participants' self-reported reflection behaviors and their design performance, guiding novice designers to reflect on the following objects may improve their ability in design: their attitudes, their ingrained beliefs and values, the contexts of artifacts being used, and the issues related to the circumstances of a given design project. In addition, even though novice designers are inclined to reflect heavily on their knowledge and stakeholders' needs, they may need additional interventions to help them reflect on critical aspects of their design processes.

Dimension III: Levels of Reflection

During a design process, designers are likely to exercise reflection on several occasions. Each time designers may reflect at a different level. Based on the results, participants indicated that the most frequent reflection that occurred during their design processes was single-loop reflection. On the other hand, the least frequent reflection that they engaged in was triple-loop reflection. Such a trend was found in the design processes of both high and low performing participants. When examining whether these three different levels of reflection would influence participants' performance, no significant relationship was found. Based on the review of literature in the area of reflective thinking, the conceptual discussions from previous studies imply that the higher the level of reflection designers can achieve, the more benefit designers can contribute to their communities (Argyris & Schön 1978; Moallem, 1998; Flood & Romm, 1996). The literature also indicates that professionals mostly utilize single-loop reflection, whereas triple-loop reflection is less likely to take place. One of very few empirical studies was conducted to investigate the impact of single-loop learning and double-loop learning on the organizational performance. The finding reveals that double-loop learning has a direct and positive effect on organizational performance because double-loop learning allows organizations to question their underlying assumptions and do things differently (Jashapara, 2003). This finding causes us to speculate that designers' higher level of reflection can yield a better performance in design. However, our results only show that high performing participants generated slightly more reflection for each level than the low performing participants. A possible explanation for such a finding may stem from our assessment of design performance. In our evaluation of novices' performance, the points of evaluation assess whether or not the solution of the design is new; if the participants employed logical reasoning and used the existing literature to carry out the design task; and if the participants applied procedures to conduct appropriate experiments to evaluate their generated solutions. The assessment overlooked the importance of evaluating whether novices' problem definition and solution generation were appropriate for improving the problematic areas and transforming society by influencing larger populations from multiple backgrounds. It may be possible that the consideration of these aspects in the performance evaluation may yield a different result.

Conclusions

The complex nature of design problems requires designers to reflect at several different points and consider various issues during a design process. Unlike expert designers, novice designers' ability to reflect can be hindered by their lack of experience and knowledge in performing design tasks. As a result, they may not engage in the kind of reflection that leads them to design a high-quality artifact. To enhance novices' design ability, many strategies can be employed to guide their reflection. A number of strategies for facilitating reflection have been proposed in the existing literature; however, there have been very few empirical studies conducted to discover designers' reflection patterns. Furthermore, the importance of reflection in performing design tasks remains in conceptual discussions. We argued that in-depth and comprehensive understanding of designers' reflection patterns and the impact of their reflection on their design performance may increase the capacity of educators and researchers to design an effective learning environment that promote novice designers' reflection.

Based on the finding of our investigation, certain patterns of reflection are found to be more instrumental in the creation of successful design. First, it is important to guide novices to begin to reflect at the early stage of their design process. If novices only reflect heavily toward the end of the project, it may be too late for their reflection to have major influences on their design decisions. Thus, the earlier designers exercise reflection, the better their design can be achieved. In regard to reflection at different design stages, Valkenburg and Dorst (1998) argued that designers should maintain a balanced reflection throughout a design process. Nevertheless, we found that for novices more reflection, particularly at the stages of goal identification, information gathering, solution generation, and solution evaluation, can increase the quality of their design. We believe that ultimately the balanced reflection can be achieved as novices gain more experience. For the objects of reflection, specific guidance on directing novices to examine their own attitudes and their ingrained beliefs and values will help them produce a more competitive design. Moreover, intentionally guiding novices to examine whether or not they examine carefully the contexts of the artifacts being operated and consider the different aspects of the circumstances of the given design task helps to enhance their ability in design as well. With respect to the level of design, the findings of our study did not support that reflection at the higher level can result in a better design. Based on our findings and the existing literature, it may be legitimate to extrapolate that reflection at a higher level leads novices to challenge their underlying assumptions of the design task. In this fashion, they will carry a different perspective to perform the given design project and create a design that leads society to a transformation.

In our present study, we hope that the findings inform educators and researchers about novice designers' reflection patterns and further help them to design an effective learning environment. In conducting the present study, we are aware of several limitations and issues that need to be considered for future research. First, it is recommended that the number of participants for such research should be increased. As designers can reflect on various things and at different times, many different aspects of reflection were identified. To investigate the salience of these different aspects of reflection on novice designers' performance, data collected from a large number of participants can shed further light on strategies to improve novices' performance by prompting them to reflect on certain aspects.

Second, the data for the present study were collected from the participants enrolled in the same course in the bioengineering department. The data to some extent may result in the issue of generalizability. To enhance generalizability, data for future studies may be collected from participants across different design courses, disciplines, and even institutions. Furthermore, we also suggest that for future study the data collection should take into account expert designers in the field. Even though our present study reveals that certain reflection patterns of novice designers will guide them to a better performance, the findings cannot sufficiently help educators and researchers to identify strategies that will lead novice designers to become outstanding practicing experts. It is plausible to speculate that the level of design performance and the reflection patterns of outstanding practicing experts are distinct from those of more experienced students. According to Atman and her colleagues' (2007) study, they compared the design processes of senior engineering students and expert practitioners by asking them to design a playground. They found that experts not only gathered more information, but the information they gathered focused on the issues related to the stakeholders and the circumstances of the given task. In addition, experts showed more concern for broader aspects such as social and cultural issues (i.e., neighborhood opinions). With data collected from both novice designers and practicing experts, educators and researchers will be able to design a learning environment that helps novices to develop their design expertise incrementally, from an inexperienced novice, to an experienced novice, and to a competent practicing expert.

The third concern for our present study is the evaluation method of designers' performance. To determine participants' performance, we adopted the evaluation method proposed by the instructor of the course as the instructor is a renowned scholar in the field of bioengineering and has taught bioengineering design for many years. The method used to evaluate participants' design performance was appropriate for capturing whether or not participants were able to design a device that satisfies its functional requirements. Nevertheless, our evaluation method overlooked some critical aspects for determining the quality of a design artifact in real-world situations. For instance, we were not able to assess whether or not participants' final design ideas could ameliorate the problematic situation fundamentally and sustainably. As Colon (2008) argued, engineers in current society should be trained to consider ethical issues and their responsibilities towards people and the environment. They should be socially responsible engineers who take into account the wider social contexts while designing. With this notion, we urge researchers to consider these broader aspects when designing an evaluation of designers' performance for future studies. With such an effort, the findings of the studies will help educators and researchers understand designers' design behaviors and design thinking in a more comprehensive manner. Furthermore, they will be able to design learning environments that guide next-generation designers to be socially responsible.

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Appendix 4.A
Reflective Thinking in Solving Design Problems Questionnaire for Eliciting Participants Reflection Patterns

Section I. Demographic Information

1. Student ID #: _________________
2. Age: ________________________
3. Gender: ☐ Male ☐ Female
4. Institution: ____
5. Department/Program: ____
6. Class Standing: ☐ Undergraduate ☐ Graduate
7. Year in the program: ☐ 1st ☐ 2nd ☐ 3rd ☐ 4th ☐ 4th+
8. Experience in Design: ☐ No Experience ☐ 1-2 years ☐ 3-5 years ☐ 5-8 years ☐ 10+ years
9. Email: ____

******* Before you begin, please read the following description.*******

What is reflection in design?

When you design a device or a system, you not only **actively think about** but also **rigorously examine** your ideas, actions, decisions, process, progress, etc. Because you are committed to creating something useful, you **change** your thoughts and/or actions during your design process to come up with better ideas or decisions. All deliberate efforts that lead to your changing thoughts or actions are considered as an act of reflection.

=== Proceed to Section II ===

Section II: When do you think reflectively?

1. The title of the project that I choose to answer this survey is:

____

To answer the rest of the questions, use this specified project as a reference.

2. Make your rating based on the project you specified above. Please **COMPARE** the frequency of your reflection occurring during each design activity and **CIRCLE** the number that best describes how frequently you exercised your reflection with using the scale of **0** (Never) to **10** (Constantly).

Design Activity	Never ⟵									⟶ Constantly
Identify the goal	0	1	2	3	4	5	6	7	8	9	10
Gather information	0	1	2	3	4	5	6	7	8	9	10
Define the problem	0	1	2	3	4	5	6	7	8	9	10
Generate solution(s)	0	1	2	3	4	5	6	7	8	9	10
Evaluate solution(s)	0	1	2	3	4	5	6	7	8	9	10
Make decision(s)	0	1	2	3	4	5	6	7	8	9	10

3. Make your rating based on the project you specified above. Please **COMPARE** the frequency of your reflection occurring during each period and **CIRCLE** the number that best describes how frequently you exercised your reflection with using the scale of **0** (Never) to **10** (Constantly).

Design Period		Never ⟵										⟶ Constantly
I	Week **4** (Sep, 07) – Week **7** (Oct, 07)	0	1	2	3	4	5	6	7	8	9	10
II	Week **8** (Oct, 8) – Week **11** (Nov, 5)	0	1	2	3	4	5	6	7	8	9	10
III	Week **12** (Nov, 06) – Week **16** (Dec, 09)	0	1	2	3	4	5	6	7	8	9	10

=== Proceed to Section III ===

Section III: What do you reflect upon?

Instruction:
Make your ratings based on the project you specified in Section II. Please read each statement carefully and **CIRCLE** the number that best represents your reflection for each statement with using the scale of 0 (Never) to 4 (Always).

The statement has happened…				
0 Never	**1 Seldom**	**2 Sometimes**	**3 Usually**	**4 Always**
0 time	1-3 times	4-7 times	8-10 times	≥11 times

Item	Never	Seldom	Sometimes	Usually	Always
1. I assessed the product feasibility based on its intended setting.	0	1	2	3	4
2. I examined whether I am proficient in using the tools I selected to deal with this design task.	0	1	2	3	4
3.I considered the lessons I learned from the difficulties I encountered in my previous design experiences.	0	1	2	3	4
4. I considered my end users' needs while designing the product.	0	1	2	3	4
5. I assessed whether I have enough relevant knowledge to carry out my design.	0	1	2	3	4
6. I checked how I felt in relation to my design progress.	0	1	2	3	4
7. I considered the applicability of ideas from my previous design tasks.	0	1	2	3	4
8. I evaluated whether the constraints I found are important to define the problem.	0	1	2	3	4
9. I paid attention to my feelings during the design process.	0	1	2	3	4
10. I examined my level of commitment to this project.	0	1	2	3	4
11. I checked my level of open-mindedness while completing the project.	0	1	2	3	4
12. I discovered inaccurate personal beliefs, which I had previously believed to be right.	0	1	2	3	4

=== Continued on Next Page ===

The statement has happened…				
0 Never	1 Seldom	2 Sometimes	3 Usually	4 Always
0 time	1-3 times	4-7 times	8-10 times	≥11 times

Items	Never	Seldom	Sometimes	Usually	Always
13. I challenged my beliefs established throughout my life (for example, personal experiences, environments, and upbringing).	**0**	**1**	**2**	**3**	**4**
14. I examined my level of responsibility during the design process.	**0**	**1**	**2**	**3**	**4**
15. I examined the appropriateness of the relevant knowledge that I used for this design project.	**0**	**1**	**2**	**3**	**4**
16. I examined whether my lens of viewing the world is inclusive for people of all backgrounds.	**0**	**1**	**2**	**3**	**4**
17. I was aware of any emotional change caused by the design progress.	**0**	**1**	**2**	**3**	**4**
18. I assessed the appropriateness of the criteria that I used to identify the goal.	**0**	**1**	**2**	**3**	**4**
19. I pondered over the stakeholders' needs during my design.	**0**	**1**	**2**	**3**	**4**
20. I referred back to my previous experiences to solve this design problem.	**0**	**1**	**2**	**3**	**4**
21. I examined whether the goals I identified could improve the problematic situation.	**0**	**1**	**2**	**3**	**4**
22. I evaluated whether the end product will be used in its intended setting based on my identified goal.	**0**	**1**	**2**	**3**	**4**
23. I took into account the end users' preferences while designing the product.	**0**	**1**	**2**	**3**	**4**
24. I examined how the contextual factors (for example, social, cultural, economical, historical) influenced my design decisions.	**0**	**1**	**2**	**3**	**4**
25. I evaluated if I utilized the budget wisely.	**0**	**1**	**2**	**3**	**4**
26. I examined if I used the available resources (for example, machines, equipment, or software) effectively.	**0**	**1**	**2**	**3**	**4**
27. I examined if I used the human resources properly.	**0**	**1**	**2**	**3**	**4**
28. I assessed if I managed the time appropriately.	**0**	**1**	**2**	**3**	**4**

=== Proceed to Section IV ===

Section IV: What is the level of your reflection?

Instruction:

Make your ratings based on the project you specified in Section II. Please read each statement carefully and **CIRCLE** the number that best represents your reflection for each statement with using the scale of 0 (Never) to 4 (Always).

The statement has happened…				
0 Never	1 Seldom	2 Sometimes	3 Usually	4 Always
0 time	1-3 times	4-7 times	8-10 times	≥11 times

Items	Never	Seldom	Sometimes	Usually	Always
1. I re-evaluated whether the criteria that I used for determining the goal are appropriate.	0	1	2	3	4
2. I evaluated whether my design attends to the needs of people of all ethnic backgrounds.	0	1	2	3	4
3. I examined whether I completed the design efficiently.	0	1	2	3	4
4. I re-examined my assumptions on the design project to refine the definition of the problem.	0	1	2	3	4
5. I evaluated whether my strategies efficiently help me reach the identified goal.	0	1	2	3	4
6. I checked whether my solution was effective in achieving the project goal.	0	1	2	3	4
7. I assessed whether my end product caters to the needs of people from different socio-economic groups.	0	1	2	3	4
8. I re-inspected my previous understanding of how I define the problem.	0	1	2	3	4
9. I considered social injustice issues when making decisions to my design.	0	1	2	3	4
10. I examined why I believed the defined goal was critical to address the problem.	0	1	2	3	4
11. I contemplated ethical concerns relative to my design task.	0	1	2	3	4
12. I evaluated whether the solution satisfied the specified goal of the project.	0	1	2	3	4

Thank you for your participation!

Appendix 4.B

Items in Reflective Thinking in Solving Design Problems Questionnaire Used for Exploring the Relationship between Novice Designers' Reflection Patterns and Their Design Performance

Dimension I: Timing of Reflection

Factor	Item	Correlation
Design stages	• Identify the goal	.332
	• Gather information	.485**
	• Define the problem	.390*
	• Generate solution(s)	.592**
	• Evaluate solution(s)	.492**
	• Make decision(s)	.496**
Design periods	• Period 1 (Week 4 – Week 7)	.513**
	• Period 2 (Week 8 – Week 11)	.505**
	• Period 3 (Week 12 – Week 16)	.696**

Note: a scale of 0 (Never) to 10 (Constantly) was employed.

Dimension II: Objects of Reflection

Factor	Item	Reliability
SELF Knowledge	• I examined whether I am proficient in using the tools I selected to deal with this design task.	.567
	• I assessed whether I have enough relevant knowledge to carry out my design.	
SELF Experience	• I considered the lessons I learned from the difficulties I encountered in my previous design experiences.	.803
	• I considered the applicability of ideas from my previous design tasks.	
SELF Feelings	• I checked how I felt in relation to my design progress.	.843
	• I paid attention to my feelings during the design process.	
	• I was aware of any emotional change caused by the design progress.	
SELF Attitudes	• I examined my level of commitment to this project.	.723
	• I examined my level of responsibility during the design process.	
SELF Ingrained Beliefs & Values	• I challenged my beliefs established throughout my life (for example, personal experiences, environments, and upbringing).	.709
	• I examined whether my lens of viewing the world is inclusive for people of all backgrounds.	
ARTIFACT Goals	• I evaluated whether the constraints I found are important to define the problem.	.560
	• I assessed the appropriateness of the criteria that I used to identify the goal.	
ARTIFACT Stakeholders	• I considered my end users' needs while designing the product.	.586
	• I took into account the end users' preferences while designing the product.	
ARTIFACT Contexts	• I assessed the product feasibility based on its intended setting.	.485
	• I examined how the contextual factors (for example, social, cultural, economical, historical) influenced my design decisions.	
CIRCUMS TANCES	• I evaluated if I utilized the budget wisely.	.396
	• I examined if I used the available resources (for example, machines, equipment, or software) effectively.	
	• I examined if I used the human resources properly.	
	• I assessed if I managed the time appropriately.	

Note: a scale of 0 (Never) to 4 (Always) was employed.

Dimension III: Levels of Reflection

Factor	Item	Reliability
SINGLE-LOOP	• I examined whether I completed the design efficiently. • I evaluated whether my strategies efficiently help me reach the identified goal. • I checked whether my solution was effective in achieving the project goal. • I evaluated whether the solution satisfied the specified goal of the project.	.748
DOUBLE-LOOP	• I re-evaluated whether the criteria that I used for determining the goal are appropriate. • I re-examined my assumptions on the design project to refine the definition of the problem. • I re-inspected my previous understanding of how I define the problem.	.717
TRIPLE-LOOP	• I evaluated whether my design attends to the needs of people of all ethnic backgrounds. • I assessed whether my end product caters to the needs of people from different socio-economic groups. • I considered social injustice issues when making decisions to my design. • I contemplated ethical concerns relative to my design task.	.902

Note: a scale of 0 (Never) to 4 (Always) was employed.

CHAPTER 5

CONCLUSION

This dissertation is undertaken to examine the role of designers' reflective thinking in solving design problems. The comprehensive model was developed to examine designers' reflection from three dimensions: the timing of reflection, the objects of reflection, and the levels of reflection. Based on the three-dimensional model, the Reflective Thinking in Solving Design Problems (RTSDP) questionnaire was created for designers to self-assess their reflective thinking during their design processes. The validity and reliability tests were performed to confirm the quality of the items. In addition, the reflection patterns of different groups of participants were examined. Similar and distinct reflection patterns of undergraduate engineering students and graduate instructional technology students were observed. For the third study, the goal was to investigate not only novice designers' reflection patterns, but also the relationship between their reflection patterns and their design performance by using the RTSDP questionnaire. The examination of the relationship between novice designers' reflection patterns and their design performance reveals that certain aspects of reflection are stronger indicators of a high-quality design. Thus, these particular patterns of reflection should be taken into account when designing a learning environment for novice designers. For the timing of reflection, instructional strategies should be provided to guide novices to begin to reflect at the onset of a design process. Also, strategies should be provided to engage designers in reflection, particularly when they are identifying a goal, gathering information, generating solutions, and evaluating solutions. In regard to objects of reflection, strategies can be identified to direct novices to reflect on the different objects and issues that may arise in a design process. Among these various objects, specific guidance can focus on encouraging novices to reflect on their attitudes, their ingrained beliefs and values, and the circumstances of the given design task. With respect to the level of design, even though the findings did not show strong relationships between designers' levels of reflection and their performance, novices who performed better showed slightly more reflection for each level. Thus, identifying strategies that prompt novices to exercise more reflection at these different levels may improve the quality of their design.

Limitations

This dissertation study is a stepping stone to achieve an ultimate goal of creating an effective learning environment that improves not only novice designers' ability to reflect but also enhances their ability to design. In conducting the present dissertation study, I am aware of several limitations and issues that need to be considered for future research. First, the number of participants for investigating the relationship between reflection patterns and design performance may be considered small, especially when the number of aspects of reflection that were identified in the three-dimensional model are taken into account. For example, there are nine objects that designers may reflect upon during a design process. To investigate the salience of these different objects of reflection on novice designers' performance, data collected from a large number of participants can shed further light on strategies to improve novices' performance by prompting them to reflect on certain aspects.

Second, for the study conducted to explore the relationship between reflection patterns and design performance, the data were collected from the participants enrolled in the same course in the bioengineering department. To enhance generalizability, data for future studies may be collected from participants across different design courses, disciplines, and even institutions.

Third, the evaluation of design performance used for the study that explores the relationship between reflection patterns and design performance may need further revision. The current evaluation overlooked some critical aspects for determining the quality of a design artifact in real-world situations. Thus, it may not sufficiently detect the influence of certain aspects of reflection on the design performance. For instance, the evaluation did not consider whether or not participants' final design ideas could fundamentally and sustainably ameliorate the problematic situation. Instead, it focused on whether or not participants concluded with a solution that satisfies their own identified goals, even though the goal of the project may not significantly lead to a positive change in the overall situations. Thus, a modification for the evaluation method of design performance may be needed.

Fourth, the RTSDP questionnaire will need further validation and modification efforts. In the validation study, the inconsistency of a few items was observed for participants' ratings on their reflection on issues related to the goals, the stakeholders, and the contexts of the artifacts to be designed as well as the circumstances of the given design task. Such inconsistency may be the result of collecting data from multiple design projects, courses, and disciplines. As each design project has its own requirements and each discipline may have different interpretations of these design issues, the inconsistency of participants' rating was likely to take place. Thus, it is recommended that further validation studies should consider collecting data from several large groups of participants who are assigned to the same design project.

Last, even though using the questionnaire may be able to effectively capture designers' reflection and give participants an opportunity to self-assess their reflection, to understand designers' reflective thinking in depth, coupling with other research methods may be necessary. In the study of exploring the relationship between reflection patterns and design performance, novices indicated that they frequently reflected on their knowledge and the issues related to the stakeholders. However, the frequent reflection did not result in a high-quality design. Thus, asking participants to document their design processes in design journals may allow us to observe the types of knowledge novices reflect upon and to probe into why reflection on certain types of knowledge does not lead designers to high performance. It is hoped that the combination of different research methods and data sources will help us understand designers' reflection both quantitatively and qualitatively.

Recommendations for Future Research

To advance our understanding of designers' reflective thinking in solving design problems and to eventually create an effective learning environment for improving novices' design ability, three directions are suggested for future study.

First, the present study primarily focused on investigating novice designers' reflection patterns and their design performance. The findings of the study may be conducive to the development of an effective learning environment that increases the novice designers' levels of performance. However, the learning environment may not help novice designers acquire sufficient knowledge, skills, and abilities to design like an expert. Previous studies have found that there is a difference in how novices and experts perform design tasks (Atman et al., 2007; Rowland, 1992). Also, some studies concluded that expert designers place more emphasis on the circumstances of the given design tasks (e.g., Kenny, Zhang, Schwier, & Campbell, 2005). Therefore, expert designers' approach is different from that of novice designers. Accordingly, investigation on the reflection patterns of expert designers will inform the design of learning environments that could prompt novice designers to engage in the critical aspects of reflection as expert designers do during their design processes.

Second, further investigation of the reflection patterns of designers in different disciplines is suggested for further study. Although common design behaviors can be found in designers across disciplines, design problems are context-dependent and domain-specific (Jonassen, 2008). Designers in different disciplines are inclined to have different approaches to solve design problems (Roozenburg & Cross, 1991). Such differences may result from the nature of a design problem. For instance, architectural design problems are perceived as loosely defined, whereas engineering design problems are regarded as more well-defined. Moreover, Lloyd and Scott (1994) found that engineering designers often use the problem-driven approach to perform design tasks. On the other hand, architect rely more on the solution-driven approach. Thus, extending this line of research to examine designers' reflection behaviors across disciplines will allow educators and researchers to design a customized learning environment for novice designers in a particular field.

Third, to develop novice designers' reflective thinking ability and improve their design expertise, a learning environment should be carefully designed. Based on the review of the literature, a range of strategies (Chapter 2) is suggested to foster novices' reflective thinking. Nevertheless, not all proposed strategies will be appropriate for all types of novice designers and assigned design tasks. Since designing learning environments for promoting novices' reflection itself is a design task, many issues should be carefully considered such as the various levels of novices' design expertise, novice designers' original reflection behaviors, and their previous related design experience. The design and the development of an effective learning environment may require several iterations and tests. Thus, the design-based research approach is recommended to achieve both theoretical and practical goals (Reeves, 2000; van den Akker, Gravemeijer, McKenney, & Nieveen, 2006; Wang & Hannafin, 2005).

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