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LEARNING, INSTRUCTION, AND COGNITION

The Impact of Metacognitive Instruction on Creative Problem Solving

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This study examined the impact of teaching creativity in the form of associative thinking strategies within a metacognitive framework. A representative sample of 30 university design students was selected from a larger section ($N = 122$) to participate in a 16-week supplemental course. Each week a new creative thinking strategy was integrated with activities to encourage metacognitive skill development. Upon completion of the course the treatment group had significantly higher scores on fluency and originality measures compared with their matched peers. In addition, students in the treatment condition received higher ratings on a summative domain-specific project judged by external design experts. Metacognitive Awareness Inventory scores increased for the treatment group but were stable over time for the comparison group.

Keywords *creative thinking, metacognition, creativity, cognition, creative development*

IT IS NOW WIDELY BELIEVED that creativity can be learned (Adams, 2001; Ritter et al., 2012; Lizarraga, Baquedano, Mangado, & Cardelle-Elawar, 2009; Scott, Leritz, & Mumford, 2004; Sternberg & Lubart, 1996) and that it is widely distributed rather than limited to those making renowned contributions in a particular field (Beghetto & Kaufman, 2007). However, Hennessey and Amabile (2010) pointed out in their review of the literature that compared with investigations focused on individual differences or affect, investigations aimed at training individuals to be more creative are relatively sparse. Current theories of learning emphasize self-regulated learning or the proactive pursuit of academic skills through goal setting, strategy selection, and monitoring of success in obtaining such skills (Zimmerman, 2008). In information processing–based theories

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of self-regulated learning, *metacognition*—the knowledge and regulation of one's own cognitive processes (Brown, 1987)—functions as a hub (Winne & Hadwin, 1998) and is a logical conduit for developing creative problem-solving approaches in the classroom. Intentional pedagogical approaches that have emphasized practice, automaticity, and the conditional understanding of metacognitive strategies have shown powerful results in, for example, areas of reading comprehension (Pressley, Gaskins, Solic, & Collins, 2006), monitoring accuracy (Hacker, Bol, Horgan, & Rakow, 2000; Nietfeld, Cao, & Osborne, 2006), writing (Harris, Graham, Brindle, & Sandmel, 2009), mathematics (Desoete, Roeyers, & De Clercq, 2003), problem solving (Delclos & Harrington, 1991), and self-regulatory processes in computer-based learning environments (Azevedo, 2005). The purpose of the present study was to test the efficacy of a pedagogical approach to facilitate creative problem solving by integrating creative thinking strategies—namely, associational strategies—with the development of metacognitive knowledge and skills.

Design is a multifaceted field that takes a user-centric problem-solving approach to understand user needs (as well as business, economic, environmental, social, and other requirements) to create successful solutions for real problems. (Shedroff, 2013). Success in the discipline relies heavily on creative thinking processes and provides a good development environment for our approach. We posit that metacognitive reflection allows designers to work off of progressively more formal theories to construct an explicit mental model (Schraw & Moshman, 1995) that allows for intentional attempts to apply their creative thinking skills to an infinite number of design applications. To date, however, there is little indication that creative strategies are being taught in a deliberate manner in design courses (Cross, 2006). Rather, methods that increase creativity are currently applied on a more informal basis in design education (Kowaltowski, Bianchi, & de Paiva, 2010). Therefore, this study aimed to examine an approach whereby undergraduate students were encouraged over time to develop a greater understanding of their own cognitive processes, how to regulate their problem-solving processes, and how to increase their ability to generate creative problem-solving solutions in design-based problems. In addition, it was important to test this approach in an ecologically valid context in order to gauge its efficacy and inform future intervention studies of likely challenges.

Research on Creativity

Creativity can be described as the ability to produce work that is novel (i.e., original and unexpected) and appropriate (i.e., useful or meets task constraints; Sternberg & Lubart, 1996). Creativity has been marginalized to some extent within formal educational contexts but many have long argued that the development of creative talent is not an educational frill but rather a central issue in the preservation of our culture (Gowan, 1972; Hennessey & Amabile, 2010; Sternberg & Lubart, 1996). It must be emphasized that creativity represents a family of skills and processes. Some researchers have concluded that a search for the essence of creativity is overwhelming unless it is studied with a domain-specific approach (Baer, 1998). There is currently a lack of agreement in the extent to which creativity is influenced by domain-specific versus domain-general processes (Baer, 2011); however, more likely it is both (Casakin & Kreitler, 2011). Given the complexity of creativity, it is important to identify the most relevant aspect of creativity for the particular domain under investigation (Taylor, 1987), especially considering that no single test of creativity will accurately represent the entire construct (Hocevar & Bachelor, 1989). The identification of a particular facet of creativity can increase the reliability and validity in a given study. The focus in the present study was on associative thinking in a problem-solving context.

The literature related to creative idea generation and associative thinking dates back to the early part of the 20th century and has continued forward (Koestler 1964, Maltzman, 1960; Mednick, 1962; Ribot, 1900; Spearman, 1931; Wallach & Kogan 1965). This research typically emphasizes the unusual cognitive recombination of stored associations. Many approaches to creativity including those described in Spearman's (1931) study are implicitly associationistic in that a creative idea results from the novel combination of two or more ideas that have been freed from their normal correlates. Similarly, Mednick's (1962) associative theory characterized creativity as the combining of mutually distant associative elements of thought. Creative individuals solve problems by juxtaposing a number of ideas not previously related to one another and consider the novel arrangement of temporarily contiguous, unusual associations with a given stimulus.

Wallach and Kogan (1965) adopted Mednick's (1962) basic theoretical view that creativity is an associative process. The idea that divergent thought largely focuses on ideational fluency led to the construction of a battery of verbal and visual tests that emphasized associative thinking. Wallach and Kogan (1965) asserted that the assessment process would yield its greatest effects if given under gamelike conditions (Wallach, 1970). One test in particular, the Similarities Test, focused on associational fluency, "tell me all the ways in which a potato and a carrot are alike" (Brown, 1989, p. 20). In contrast, the Remote Associates Test developed by Mednick (1962) deals with an individual's ability to identify a common connection in divergent topics. The test presents students with a set of words and requires them to identify a common word that unites them in a unique way. The widely used Torrance Test of Creative Thinking (Torrance, 1974) works in a similar fashion; it presents pictures and asks examinees to either draw pictures with titles or to provide questions, reasons, consequences, or different uses for specific images.

Current theories represent the development of creativity as a continuum. This continuum starts with novel and personally meaningful representations during knowledge acquisition that are filtered through background experience and are referred to as *mini-c creativity* (Beghetto & Kaufman, 2007). Next along the continuum are external representations of creativity from everyday experiences termed *little-c creativity*. Creativity as represented by professionals who have not reached eminent status can be termed *Pro-c creativity* (Kaufman & Beghetto, 2009). Last, at the pinnacle of the creativity continuum are eminent examples of creativity that are widely recognized and known as *Big-C creativity*. One distinction going from mini-c to Big-C is transitioning from personally relevant and unrecognized creative processes to externally recognized creative products and outcomes.

Research supports the notion that carefully designed interventions can have a positive effect in increasing various creative abilities and that these outcomes extend across criteria, settings, and target populations (Hennessey & Amabile, 2012; Scott et al., 2004). Commonalities across successful creativity training studies include the use of extended/distributed training sessions, a focus on problem-solving and cognitive strategies, and the use of meaningful or domain-relevant tasks. Kvashny (1982) found increased benefits from design-based creativity training that consisted of active exercises developed to enhance creativity over those consisting only of reading books on the subject. More recently, Anderson (2002) took on such an approach when assessing the role of metacognition in the classroom by including the following five components: (a) preparing and planning, (b) selecting and using strategies, (c) monitoring strategy use, (d) orchestrating various strategies, and (e) evaluating strategy use. Anderson's assessment was focused on teaching and learning a second language; however, the components apply to creative problem solving across disciplines. Anderson (2002) proposed that teachers help students evaluate their strategy use by asking them to respond thoughtfully to the following questions:

1. What am I trying to accomplish?
2. What strategies am I using?
3. How well am I using them?
4. What else could I do?

Similarly, Swartz (2001) presented a carefully sequenced classroom-based curriculum of selected cognitive and metacognitive operations that included (a) teaching explicit cognitive strategies and how the strategies related to creative thinking; (b) providing significant opportunities for students to practice planning, monitoring, and evaluating their thinking; (c) prompting active engagement and creative thinking within specific content; and (d) providing practice sessions for the application of creative thinking in new contexts. The approaches used by Anderson (2002) and Swartz (2001) align well with current problem-solving studies that emphasize metacognitive prompts (Davis, 2003; Hoffman & Spatariu, 2008).

Davis and Rimm (1985) suggested that creative abilities could be strengthened through practice in creative thinking exercises, such as those that promote divergent thinking. The essential techniques or creative strategies, according to Davis and Rimm (1985) are brainstorming, attribute listing, morphological synthesis, idea checklist, and synectics. Pesut (1990) also suggested that fundamental skills of creativity include brainstorming, synectics, attribute listing, and free association. In the present study, multiple creative strategies are introduced with the understanding that each strategy is similar in allowing the individual to externalize his or her ideas and make associations. By introducing a diverse range of creative strategies, this allows the problem solver or group to develop ideation strategies best suited to their skills, needs, and the type of problem.

More recent studies have highlighted the importance of extended interventions that allow for distributed practice sessions over time. Garaigordobil (2006) compared 10–11-year-old Spanish elementary school students who, throughout the school year, participated in weekly activities that emphasized creativity through play and cooperation with a comparison group of students. Results revealed significant advantages for the treatment group on verbal creativity and graphic-figural creativity. Benedek, Fink, and Neubauer (2006) used an extended number of computer-based training sessions to examine ideational fluency in Austrian adults. They found that participants in two different treatment groups outperformed a control group on ideational fluency (but not originality) at the completion of the training sessions. Studies with mixed findings tend to be limited by brief interventions. For example, Dow and Mayer (2004) had college students individually read training packets for 15 min to prepare them to solve insight problems on verbal, mathematical, and spatial tasks. Only those in the spatial conditions showed advantages from their training.

Metacognition and Instruction

A taxonomy of metacognition includes *knowledge of cognition* and *regulation of cognition* (Baker, 1989; Schraw & Moshman, 1995). Knowledge of cognition consists of explicit knowledge of one's declarative and procedural memory, as well as *conditional knowledge*— knowledge about why, when, and where to use strategies. Regulation of cognition consists of knowledge about planning, monitoring, and evaluation. It is important to note that learners must not only continue to gain a greater understanding of their knowledge and strategies as they learn, but also be able to effectively regulate this knowledge as they cognitively manage tasks online in real time. The regulation aspect requires the learner to engage in the reciprocal processes of accurate monitoring and control processes that allow for adjustments to be made in response to monitoring feedback (Nelson & Narens, 1994). However, neither of these processes are a given in the absence of feedback or training (Nietfeld & Cao, 2005; West & Stanovich, 1997). Thus, the relation between *knowing* and *doing* becomes essential for effective problem solving and ensuring that a cognitive goal has been met. Metacognitive monitoring and regulation processes are pervasive throughout self-regulated learning models (Butler & Winne, 1995). Learning environments that provide the potential to develop self-regulated learning are those that support autonomy and control processes (Pintrich, 2000). However, the extent to which metacognitive processes are applied by the learner will largely depend on a number of sources of motivation (e.g., self-efficacy) being present (Zimmerman & Moylan, 2009).

The infusion of metacognitive training within instructional contexts has a rich history in content domains such as a mathematics, reading, and writing and also with problem solving more generally. For example, Jausovec (1994) conducted a series of studies designed to investigate the influence of metacognition on problem-solving performance. The results suggested that more proficient college-age problem solvers used more sophisticated metacognitive strategies, monitored their performance more accurately than did less-proficient problem solvers, and performed better on open-ended (creative) problems. Jausovec (1994) concluded that explicit metacognitive instruction is necessary in educational settings to improve problem-solving performance. Evidence of successful explicit instruction is widely evident in the literature particularly with regard to improvement in monitoring and evaluation skills. Successful reading intervention programs such as transactional strategies instruction (Brown, Pressley, Van Meter, & Schuder, 1996; Pressley & Gaskins, 2006) have emphasized the explicit teaching of cognitive strategies and comprehension monitoring tactics to maintain and apply their use. The process of writing is so uniquely intertwined with metacognitive processes (Hacker, Keener, & Kircher, 2009) that successful instructional programs emphasize strategy instruction with a self-regulated approach that includes an emphasis on teaching self-monitoring skills and peer interaction (Harris, Graham, & Mason, 2006).

In the classroom, many approaches for metacognitive instruction can be recommended from prior research. One approach is for teachers to model their own metacognition for students as they solve a problem. When modeling, thinking aloud can assist students if teachers discuss their cognitive processes in real time (i.e., how to perform a task), and fix-up strategies can be provided to aid with monitoring and regulation processes (Huff & Nietfeld, 2009). Recently, research has shown the importance of socially shared metacognition for problem-solving effectiveness (Iiskala, Vauras, Lehtinen, & Salonen, 2011) and coregulation of learning in the active construction of knowledge (Hadwin, Järvelä, & Miller, 2011). One important caveat related to student outcomes is that student self-reported knowledge of strategies does not necessarily translate into the application of such strategies in meaningful contexts. Scherer and Tiemann (2012) examined problem-solving competencies of secondary students on complex chemistry problems and found that strategy knowledge was distinguished from the problem-solving process itself and that it did not directly relate to performance. Thus, it is crucial that instructional practices (a) focus not only on strategic knowledge but also on conditional knowledge; and (b) provide extensive practice opportunities to apply this knowledge. This can be most effectively accomplished through a spacing approach (Son & Simon, 2012) that distributes practice sessions over time and reduces the tendency for learners to be overconfident regarding their learning. Last, it is important to recognize the need for the teacher to have highly developed metacognitive knowledge because this leads to a greater pedagogical understanding of metacognition (Wilson & Bai, 2010).

Instructional approaches ideally assist students in constructing an explicit mental model of metacognitive thinking processes (Schraw & Moshman, 1995). Mental models are necessary to monitor performance and also in the development of self-regulatory skills. There are at least three levels of metacognitive mental models ranging from the basic tacit model, to the intermediate informal model, and eventually a sophisticated formal model (Schraw & Moshman, 1995). A *tacit model* is an implicit understanding of one's cognitive processes that lacks any explicit awareness that one possesses a model (McCutcheon, 1992). Students at this level may be capable of solving complex problems but are unable to explain how they reached a solution. An *informal model* is more advanced than the tacit model in that the former is partially accessible to conscious introspection, scrutiny, and revision. This introspection allows for the revision of one's model over time. Informal models are fragmentary in that students are aware of some of their beliefs and assumptions but have not yet constructed an explicit theoretical structure that integrates and justifies these beliefs (Schraw & Moshman, 1995). A *formal model* is an explicit, explanatory representation of a complex phenomenon such as creative thinking.

Students who have developed a formal model are explicitly aware of their purposeful efforts to construct and modify metacognitive theories. Schraw and Moshman (1995) suggested that learners develop metacognitive theories through cultural learning, individual construction, and peer interaction. Cornoldi (1998) echoed this perspective in his definition of *metacognitive attitude* as the general tendency of a person to develop reflection about the nature of his or her own cognitive ability and to think about the possibility of extending and using this reflection. The instructional intervention in the present study aimed at providing opportunities for students to develop increasingly complex metacognitive mental models. We predicted that this development, combined with strategy instruction focusing on conditional knowledge and its application, would facilitate creative problem solving.

Present Study

The field of design emphasizes innovation and offers an appropriate context in which to measure creativity given that the problems in this domain are open-ended with multiple pathways for solutions. As such, we used a semester-long intervention for first-year design students that emphasized associative thinking skills. A supplemental weekly 1-hr course was created in which a representative sample of students from a larger introductory course practiced strategies emphasizing associative thinking couched within a pedagogical approach that emphasized metacognitive knowledge and skills. At the end of the semester, this treatment group was then compared with their peers from the introductory course on measures of creative problem solving that emphasized associative thinking. Therefore, this study intended to teach creative problem-solving strategies through an approach that simultaneously emphasized metacognitive awareness, monitoring, and regulation. We predicted that the emphasis on metacognition would function as a catalyst to support students' approaches when performing tasks that required associative thinking and also improve students' metacognitive abilities within the domain of design.

The present study aimed to address the following primary research question:

> What effect does the integration of creative thinking strategies within a metacognitive instructional framework have on creative problem solving?

Following prevalent definitions of creativity (Hennessey & Amabile, 2010; Sternberg & Lubart, 1996), we employed outcome measures to assess creativity through both novel responses and contextual appropriateness. The Similarities Test (Wallach & Kogan, 1965) and the Remote Associates Test (Mednick, 1962) represented novel responses while an authentic domain-specific design-based task represented appropriateness. Zeng, Proctor, and Selvendy (2011) argued that using divergent thinking as the sole indicator of creativity, as is often done, excludes the appropriateness dimension of creativity and therefore measurements suffer in various components of validity-related evidences (e.g., construct, ecological) and also neglects domain specificity and expertise.

The instructional intervention contained no additional instruction related to the larger introductory course. Rather, the intervention focused on fostering associative thinking more generally through the integration of metacognitive instruction that emphasized the monitoring and control of various creative thinking strategies. Given that students in the treatment group did not receive more instructional time related to course content, we decided not to include an additional control group to receive a supplementary hour of instruction each week from the larger sample of students. Moreover, given that the study was field-based and conducted in an ecologically valid context, the formation of an additional augmented-instruction comparison group would likely breach ethical best practices for the course as a whole and result in a disadvantage for the remaining students who were not selected for either group.

A secondary purpose of the study was to investigate (a) the effect of the integration of the creative thinking strategies in a metacognitive instructional framework on self-report metacognitive awareness and (b) the relation between creativity scores and self-report metacognitive awareness. Recent evidence has shown the weakness of relying upon self-report measures (Winne, 2010), yet little work has examined how prevalent self-report measures such as the Metacognitive Awareness Inventory (Schraw & Dennison, 1994) relate to creativity or how stable such measures themselves are over time.

METHOD

Participants

Participants for the treatment condition were drawn from a required course entitled Design Thinking for freshman design students at a large university in the Southeastern United States. This course included a discussion of design thinking principles in the various design disciplines.

TABLE 1
Treatment Population Distribution ($n = 30$), by Gender and Major

	Female		*Male*		*Total*	
Major	n	%	n	%	n	%
Art and design	3	10.0	3	10.0	6	17.0
Architecture	3	10.0	5	16.7	8	30.0
Graphic design	7	23.3	3	10.0	10	33.0
Industrial design	0	0.0	3	10.0	3	10.0
Landscape architecture	2	7.0	1	3.0	3	10.0
Total	15	50.0	15	50.0	30	100.0

It was intended to give a variety of perspectives from which to proceed into the design process. Participation in this study required students to enroll in an additional weekly 1-hr course for which they received two additional credit hours. Students were selected to participate in the treatment condition by a stratified random sampling process using creativity test scores from the previous semester, major, and gender as sorting variables from which to draw students ($n = 30$; 50% female) for the Design Thinking Explorations course (see Table 1). Grade point average was not used in the selection process because students were in their first semester of courses at the university and because of the lack of variance between preexisting high school grade point averages. The purpose of this process was to assign a random sample of students to the treatment condition that would be representative of the larger group of students ($N = 118$) taking the Design Thinking course. Of the participants who were invited to take part in the treatment condition, only one refused. All participating students in the treatment and resulting comparison condition ($n = 88$) were given informed consent forms regarding the nature of this study and then asked to participate.

Materials

Creativity Tests

Two tests of creativity, and more specifically associative thinking, were selected for this study: the Similarities Test (Wallach & Kogan, 1965) and the Remote Associates Test (Mednick, 1962). The Similarities Test (e.g., see Appendix A) is a measure of divergent thinking where participants were asked to list all of the ways that they could think of that particular pairs of items were alike. Ten item pairs were given at each administration. A fluency score was determined by adding the number of valid responses provided across the 10 items on the test. An originality score was also computed by totaling the number responses a participant generated that were given by no more than 5% of all respondents. These two scores were computed independently, and the originality responses were included within the all-inclusive fluency scores. We did consider the possibility that more common associations would occur earlier in the response period and more unique associations later in a sequence and that individuals who are able to produce a large number of associations might also produce a greater number of unique answers. Given that responses of greater stereotypy are likely to come early in a sequence, even in the case of creative persons, no time limit was imposed on the task in order to provide sufficient time for more unique responses to emerge. The range in response completion time for the Similarities Test and the Remote Associates Test combined was approximately 30 to 90 min. Previous validation of the creativity instruments included reliability and validity studies. Using the Spearman-Brown split-half reliability coefficient the Similarities Test was found to have a .87 reliability score for the originality score and a .93 reliability score for total correct item score (Wallach & Kogan, 1965). In addition, the Similarities Test has been shown to have high correlations with Wallach and Kogan's (1965) other subtest measures of creativity and no correlation with a variety of measures of intelligence. Two individuals scored all of the Similarities items, determined discrepancies, and resolved discrepancies through discussion. In this study, split-half reliabilities (with Spearman-Brown correction) were .87, .88, and .96, respectively, for the three administrations of the Similarities Test for fluency; and.78, .78, and .94, respectively, for the three administrations of the Similarities Test for originality.

Unlike the Similarities Test, the Remote Associates Test is a measure of convergent thinking as it applies to creativity. The objective is to provide a single term that fits as an associational bridge to unite three words. Only one word constitutes the correct answer to a given problem. For example, *cheese* would be the correct response to the triad *rat*, *blue*, and *cottage*. The score for this test, then, was number of items correctly answered out of 50 total items. In two separate validation studies, the Spearman-Brown reliability for the Remote Associates Test was .92 and .91, respectively (Mednick, 1962). The Remote Associates Test also showed a high positive correlation ($r = .70$) with expert ratings of the creativity of a group of practicing architects. In this study, the coefficient alphas were .86, .80, and .86, respectively, for the three administrations of the Remote Associates Test.

Metacognitive Awareness Inventory (Schraw & Dennison, 1994)

This inventory was used to measure self-report knowledge and regulation of cognition. It included 52 items that were reported on a 5-point Likert scale ranging from 1 (*strongly disagree*) to 5 (*strongly agree*). Knowledge of cognition includes dimensions related to declarative, procedural, and conditional knowledge. A sample item is "I am a good judge of how well I understand something." Regulation of cognition measures control aspects of metacognition that include planning, information management strategies, comprehension monitoring, debugging strategies, and evaluation. A sample item under this facet is "I think of several ways to solve a problem and choose the best one." An overall sum score across the two facets was used for analyses in the present study. The Metacognitive Awareness Inventory has been shown to be internally reliable and have a test–retest reliability of .85 (Dennison, 1997). Furthermore, Hammann (2005) found the inventory to have strong predictive validity for test performance and self-monitoring in academic tasks. A sum score was computed across all items and used in the analyses. In this study, the coefficient alphas were .91, .92, and .93, respectively, for the three administrations of the Metacognitive Awareness Inventory.

Design Thought Model

Students' creative and metacognitive thinking was assessed through their final design project for the Design Thinking course. This summative, performance-based project termed the *design* *thought model* required students to construct a three-dimensional personal philosophy of their design process (see Figure 1). The project was selected because of its non–discipline-specific nature and emphasis on creative thought processes. The project guidelines were provided at the beginning of the semester to allow students the duration of the semester to consider their design (see Appendix B). The process required students to first provide a written summary of the design process during the semester. Next, they transformed their written explanation into a three-dimensional expression of their philosophy. Last, at the end of the semester, an exhibit was held in which students were required to present and orally communicate how their philosophy was represented through their model to neutral judges. Giving students the opportunity to create a physical artifact afforded students the opportunity to externalize the cognitive processes of design. All students in the Design Thinking course completed the design thought model and were given the same directions for the project with no differential level of practice or preparation between the treatment and comparison group.

During the design thought model exhibit, each student was given the opportunity to present his or her model to external reviewers (design professionals from across the United States who were representative of each of the disciplines in the College of Design who were blind to study conditions) in addition to their course instructor. The evaluation process largely followed the consensual assessment technique recommended by Amabile (1982). The judges, who were experts within the domain of design, made initial assessments independently, assessed technical as well as creative and metacognitive dimensions of the design thought model, and they rated products from a relative perspective. The only deviation from the consensual assessment technique was that judges were not able to review the design thought models in a fully randomized order because of the nature of the event and procedural limitations. A student's grade was based on a sum of four categories (craft of the model, rigor of the concept, communication, and metacognitive thinking) that was described in detail for the students in a comprehensive scoring rubric and also used by the external reviewers (see Table 2). These categories represent a measure of students' metacognitive thinking ability including the clarity of ideas, depth of thought and reflection, and an awareness and understanding of one's own cognitive processes. Each project was evaluated by three external reviewers from a larger group of individuals who worked on a rotation system to evaluate all the projects at the event. At the culmination of the exhibit, all external reviewers and instructor met to discuss any discrepancies in scoring across the four categories. After the discussion, student scores were determined with an average score across the ratings of the three external reviewers and instructor if discrepancies still existed.

Procedure

A summary of the procedural timeline is provided in Figure 2. Participants completed the Metacognitive Awareness Inventory and each of the creativity tests three times during the course of the study. Each administration was conducted with a unique parallel form of the test. All students were tested at the beginning and end of the semester preceding the Design Thinking Explorations course and again at the end of the semester during which the course occurred. Thus, the tests were given at three times during the freshman year for all students. A more detailed description of the curriculum and procedures within the Design Thinking Explorations follows.

FIGURE 1 Design thought model.

TABLE 2
Design Thought Model Scoring Rubric for External Reviewers

Section	*Number of points*	*Description*
Craft of the model	10	Construction and representation of the physical artifact
Rigor of the concept: Precision of thinking	10	Exploration and articulation of the concept, refinement and detailed representation of thinking
Communication: Accurate representation of the idea	10	Congruence between verbal and physical representations, physical model serves to communicate ideas above and beyond the verbal presentation
Metacognitive thinking	10	An awareness and understanding of one's own thinking process. Metacognition begins with an awareness among thinkers that metacognition exists, differs from cognition, and enhances creative thinking. Beyond this basic awareness metacognition requires *knowledge of cognition* and *regulation of cognition*. • Knowledge of cognition includes what students know about themselves, thinking strategies, and conditions under which strategies are most useful. • Regulation of cognition corresponds to knowledge about the way students plan and implement thinking strategies, monitor and correct errors, and evaluate their thinking.

Description of the Design Thinking Explorations Intervention

The course focused on improving students' creativity within a metacognitive framework. Specific creative thinking strategies were introduced, learned, and practiced as action-oriented metacognitive skills (see Appendix C for course schedule). The instructor for the larger Design Thinking course was not involved in the present study; however, one of the authors (Hargrove) was the instructor for the course. Seminar instruction focused on developing conditional knowledge to enhance students' creative thinking abilities, particularly the creative skill of association. The

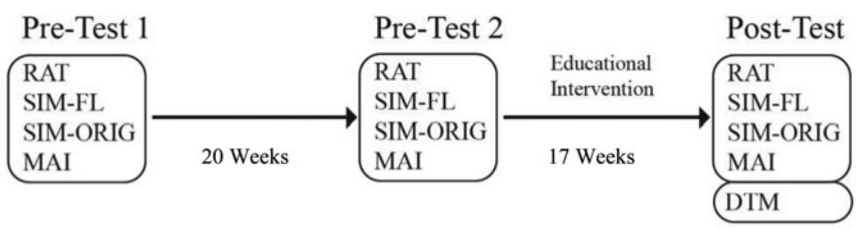

FIGURE 2 Data collection timeline.

framework was situated within a self-regulated metacognitive approach to design thinking. A topical approach was taken each week.

At the initial stages of the course, students were provided with information about the meaning and importance of metacognition as well some background on the knowledge and regulation of cognition facets subsumed within metacognition. This grounding was followed by a discussion of the importance of metacognition within design education in order to establish a level of personal relevance for the students at the beginning of the seminar. In addition, students learned about the relation between cognition and metacognition. A standard format was maintained for each weekly session. Instruction began each session by introducing a single creative strategy. After new strategies were introduced, a discussion related to all three knowledge components (conditional, procedural, and declarative) followed. While a metacognitive approach to creative thinking remained constant, various creative strategies were introduced, learned individually, and then later practiced as a skill set. The focus of the class time was on exercises and examples that encouraged student involvement and offered perspective.

The assumption of this study was that improving metacognitive thinking would enhance creative thought. A number of instructional strategies were used in the Design Thinking Explorations course including direct instruction, modeling, and paired problem solving with a common emphasis on the active construction of knowledge. For example, paired problem-solving activities required students to work in pairs to engage in think-aloud tasks, with one student solving a problem and reporting aloud what he or she was thinking. Thus, the core of the educational intervention was interactive and involved activities and exercises allowing students to experience using the creative strategies for themselves. This open learning environment increased motivation as students became active and willing participants in activities. The instructor also used a taxonomy of subcomponents from the regulation of cognition dimension of metacognition during activities in order to guide students and encourage self regulation. Students practiced these subcomponents (e.g., identifying potential obstacles, knowing when a subgoal has been achieved, evaluating the appropriateness of procedures used) when solving problems and were encouraged to extend their use to projects in their design studios. Last, students were provided with opportunities to analyze how numerous expert designers engage in various kinds of thinking operations. To accomplish this, students viewed, listened to, or read examples or case studies of thinking in action, and with instructor assistance identified the kinds of cognitive and metacognitive strategies and skills used by the various experts. In addition, students in the Design Thinking Explorations course were challenged to find and bring to class new examples of metacognitive thinking by experts in various domains (design and otherwise). To summarize, the major tenants of the instruction included the following:

1. Assist students' development and learning of explicit cognitive strategies that inform and organize the way that they engage in specific types of creative thinking (*knowledge of cognition*);
2. Include significant opportunities for students to plan, monitor and evaluate their thinking during instruction (*regulation of cognition*);
3. Conduct instruction in an open learning environment where advanced creative thinking is modeled and where students are given opportunities to reflect on their thinking;
4. Prompt creative thinking processes within the context of actual domain-specific content that students are learning (*active construction of knowledge*);

5. Ensure high-quality practice of specific strategies and concepts after instruction to encourage the internalization and self-regulated use of creative strategies in new contexts.

A number of tools such as the strategy evaluation matrix, the regulatory checklist, a personal reflection journal, and a metacognitive mental model matrix served to assist students in monitoring their metacognitive thought processes. Students were asked to complete a strategy evaluation matrix over the duration of the semester (Schraw, 1998). The strategy evaluation matrix was introduced during the first week of the semester, and the students were asked to incorporate each new strategy into their matrix. Students were given time to reflect individually and in small groups about strategy use. The matrix required students to record how to use, when to use, and why to use portions for each strategy. Students were expected to revise their strategy evaluation matrixes as if they were a mini portfolio. The strategy evaluation matrix served three very important functions: (a) promoted strategy use, (b) promoted explicit metacognitive awareness, and (c) encouraged students to actively construct knowledge.

The use of a regulatory checklist (Schraw, 1998) provided an overarching heuristic that facilitated regulation of cognition. It provided prompts for students to implement in a systematic sequence to help them control their performance. Students were encouraged to use their regulatory checklist in all classroom problem-solving examples. The regulatory checklist included four prompts for all three facets: (a) planning (e.g., "What is my goal?"), (b) monitoring (e.g., "Am I reaching my goals?"), and (c) evaluation (e.g., "What strategies worked?").

Journal keeping was a form of independent reflection used to document an increasing understanding of one's metacognitive knowledge. The journals provided the opportunity for students reflect on their problem-solving process through writing and illustrations. This record also provided an opportunity to revisit initial perceptions, compare the changes in those perceptions with additional experience, and recall the success and the failures through the experimentation with cognitive strategies.

Assessment was an important part of tracking students' pursuit of a conceptual level of understanding about their metacognitive process and in their construction of a mental model for a creative approach to design-based problems. Therefore, during the first session, students self-assessed where they currently stood in terms of the use of cognitive strategies using a matrix that was adapted from Wiggins and McTighe (2005) that we refer to as the metacognitive mental model matrix. This activity was used as a baseline for periodic reevaluation during the course. It was important to formulate a plan to help students move from implicit to informal to formal mental models, or at least make them aware that these different stages existed and why one should strive toward a formal model. Making one's mental model explicit and accessible to conscious introspection was a significant challenge for many students. However, this introspection that allowed for scrutiny and revision of one's model over time provided the potential for advancement to a higher, more formal model. The goal was for students to develop an explicit, explanatory, representation of creative thinking over time. During the latter part of the semester, a greater emphasis was placed upon reflection of their mental models. Each week a different facet of the matrix was discussed in class and what it would take to move through the different levels. Students were encouraged to have an accurate self-assessment and then identify strategies for advancement to higher levels. Students also met individually with the instructor to discuss strategies for advancement.

Data Analysis

Descriptive and correlational statistics were first analyzed. Next, data analysis procedures consisted of a comparison of the treatment and comparison groups on measures from the Similarities Test (fluency and originality) and on the Remote Associates Test using a repeated-measures multivariate analysis of variance. This was followed by a repeated-measures analysis of variance to examine changes in the Metacognitive Awareness Inventory within and across groups. Last, we used *t* tests to compare the treatment and comparison groups on scores from the design thought model.

RESULTS

Descriptive statistics including means and standard deviations for the present study variables are presented in Table 3 and bivariate correlations are provided in Table 4. The remainder of this section is organized by the primary research questions.

What Effect Does Metacognitive Instruction Have on Creative Problem Solving?

This question was addressed by examining group differences between three measures of creativity that included similarities fluency, similarities originality, and on the Remote Associates Test. Next, differences on the design-based task were determined using the overall and metacognition-specific ratings on the design thought model.

We conducted a 2 (groups) × 3 (measures of creativity) repeated-measures multivariate analysis of variance to investigate differences between the treatment and comparison group with regard to performance on the similarities fluency, similarities originality, and the Remote Associates Test. We were interested in potential interaction effects resulting from the treatment conditions. Therefore, we conducted within-subjects analyses across the three testing sessions, by group, across the three tests. We found a significant interaction for group across testing sessions, Pillai's trace, V = .57, $F(6, 107) = 23.53$, $p < .001$, $\eta_p^2 = .57$. Univariate tests revealed significant interactions within each different test, by condition: fluency, $F(2, 224) = 54.28$, $p < .001$, $\eta_p^2 = .33$; originality, $F(2, 224) = 71.06$, $p < .001$, $\eta_p^2 = .39$; and the Remote Associates Test, $F(2, 224) = 14.35$, $p < .001$, $\eta_p^2 = .11$.

For fluency, simple effects follow-up tests revealed that the treatment group scored significantly higher ($F[118] = 81{,}03$, $p < .001$, $\eta_p^2 = .41$) on the posttest than did the comparison group (see Figure 3). We found no significant differences for either of the two pretest scores. For originality, simple effects follow-up tests revealed that the treatment group scored significantly higher ($F[118] = 131.75$, $p < .001$, $\eta_p^2 = .53$) on the posttest than did the comparison group (see Figure 4). No significant differences were found for either of the two pretest scores. For the Remote Associates Test, simple effects follow-up tests revealed that the treatment group scored significantly higher ($F[117] = 15.20$, $p < .001$, $\eta_p^2 = .12$) on the posttest than did the comparison group (see Figure 5). However, the group differences were the result of a decrease in scores by the comparison group rather than an increase in scores by the treatment group. No significant differences were found for either of the two pretest scores.

TABLE 3
Means and Standard Deviations for Study Variables

Group	*Pre 1 Metacognitive Awareness Inventory*	*Pre 1 Remote Associates Test*	*Pre 1 Sim-Fl*	*Pre 1 Sim-Orig*	*Pre 2 Metacognitive Awareness Inventory*	*Pre 2 Remote Associates Test*	*Pre 2 Sim-Fl*	*Pre 2 Sim-Orig*	*Post Metacognitive Awareness Inventory*	*Post Remote Associates Test*	*Post Sim-Fl*	*Post Sim-Orig*	*Design thought model*
Treatment	191.87 (18.41)	19.87 (7.29)	74.13 (28.15)	21.73 (14.85)	192.73 (16.94)	22.0 (5.62)	59.37 (24.68)	14.17 (7.80)	202.27 (16.08)	22.77 (5.95)	102.97 (40.16)	48.40 (22.29)	4.16 (0.496)
Comparison	193.21 (19.51)	21.68 (7.95)	71.26 (29.23)	18.87 (13.96	193.34 (21.59)	22.30 (5.86)	55.57 (22.52)	11.63 (7.90)	197.81 (22.15)	17.12 (7.13)	52.99 (19.85)	15.42 (9.18)	3.932 (0.524)
Total	193.37 (19.86)	21.23 (7.80)	71.97 (28.88)	19.57 (14.20)	192.88 (19.17)	22.22 (5.78)	56.53 (23.03)	12.27 (7.92)	198.93 (20.83)	18.55 (7.26)	65.48 (34.06)	23.67 (19.74)	3.99 (0.525)

Note. Sim-Fi = Similarities Fluency, Sim-Orig = Similarities Originality.

TABLE 4
Correlations Between Study Variables

Variable	*1*	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*	*10*	*11*	*12*	*13*
1. Pre 1 Metacognitive Awareness Inventory	1	−.09	.30	.15	.73**	−.22	−.03	.04	.29	−.25	.00	−.09	.22
2. Pre 1 Remote Associates Test	−.07	1	−.16	−.15	.08	.19	.06	.10	−.29	.50**	−.31	−.26	.03
3. Pre 1 Sim-Fl	−.15	.14	1	.91**	.27	−.10	.43*	.45*	−.14	.08	.64**	.43	.18
4. Pre 1 Sim-Orig	−.20	.11	.78**	1	.16	−.11	.36	.38*	−.19	.04	.57**	.44*	.23
5. Pre 2 Metacognitive Awareness Inventory	.73**	−.07	.01	−.08	1	−.11	−.12	−.08	.35	−.01	−.09	−.22	.13
6. Pre 2 Remote Associates Test	.11	.48**	−.01	−.07	.10	1	−.03	.07	−.18	.48**	−.16	−.08	.08
7. Pre 2 Sim-Fl	−.08	.12	.62**	.52**	−.01	.04	1	.88**	−.55**	.31	.57**	.50**	.06
8. Pre 2 Sim-Orig	−.16	.11	.44**	.56**	−.13	−.11	.81**	1	−.56**	.32	.49**	.46*	.19
9. Post Metacognitive Awareness Inventory	.66**	−.24*	−.05	−.19	.81**	.00	−.03	−.14	1	−.21	−.17	−.18	.15
10. Post Remote Associates Test	−.10	.58**	.19	.06	−.04	.61**	.20	.06	−.10	1	.11	.20	−.04
11. Post Sim-Fl	−.09	.18	.61**	.41**	.04	.08	.56**	.42**	−.03	.22*	1	.91**	.28
12. Post Sim-Orig	−.05	.16	.35**	.33**	.04	.02	.33**	.36**	−.04	.06	.81**	1	.31
13. Design thought model	.10	.06	.31**	.28**	.27*	.01	.22*	.20	.18	.08	.38**	.42**	1

Note. Values for treatment group above the diagonal and values below the diagonal for comparison group. Sim-Fi = Similarities Fluency, Sim-Orig = Similarities Originality.
$^{*}p < .05$. $^{**}p < .01$.

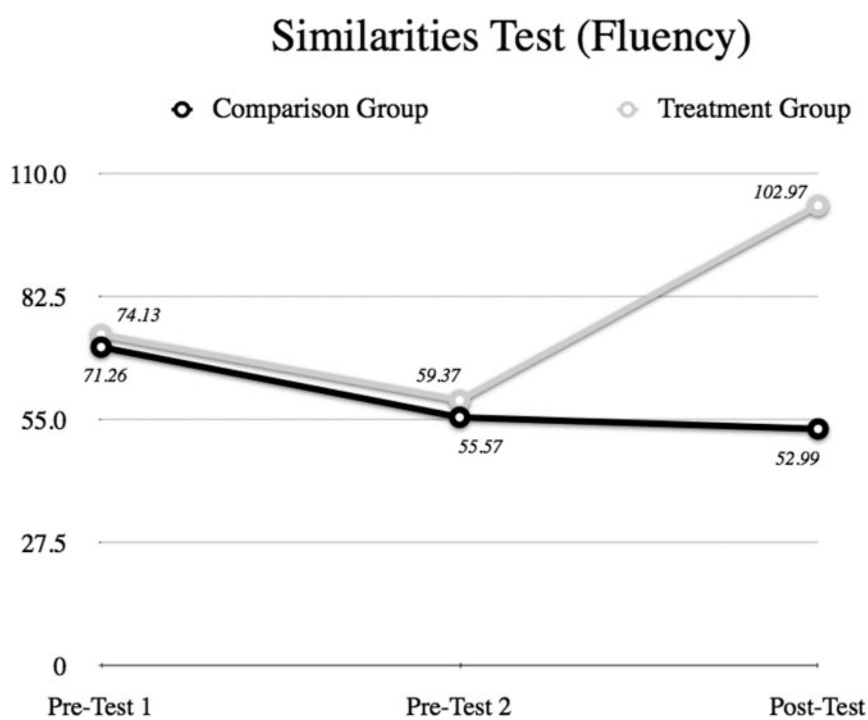

FIGURE 3 Similarities test fluency results.

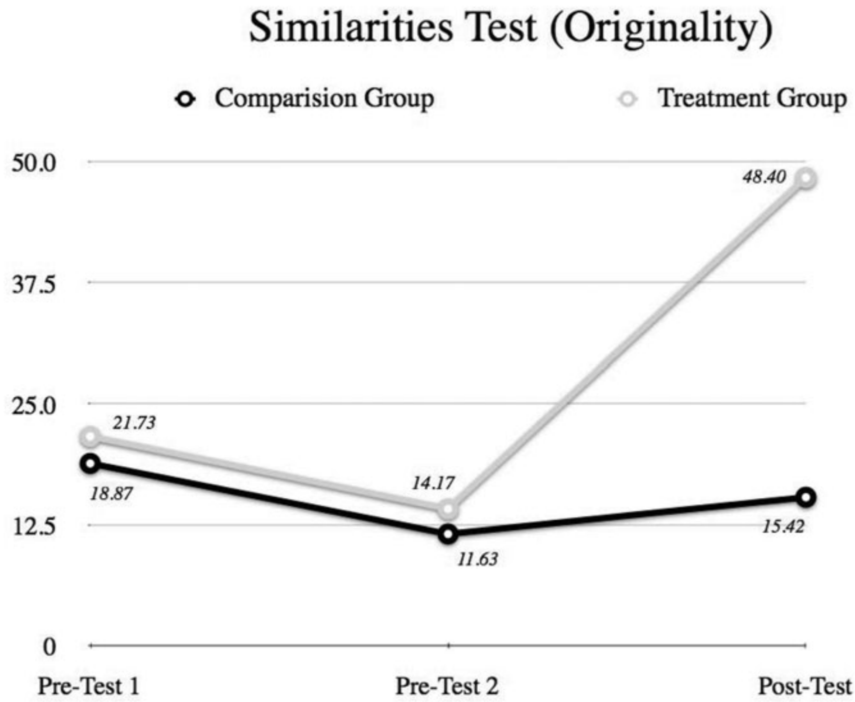

FIGURE 4 Similarities test originality results.

Design Thought Model

We used independent measures *t* tests to examine group differences in overall scores and metacognition specific ratings from the design thought model activity. Results revealed that the treatment group scored significantly higher than did the comparison group on both the overall design thought model score ($t[114] = 4.73, p < .001, d = 1.11$) and on the metacognitive specific rating ($t[114] = 2.07, p = .04$, Cohen's $d = .45$).

What Effect Does Metacognitive Instruction Have on Metacognitive Awareness?

A 2 (groups) × 3 (sessions) repeated-measures analysis of variance revealed a significant main effect of time across the three testing sessions, $F(2, 228) = 13.54, p > .001$, partial $\eta^2 = .106$. We found no significant interaction. Pairwise Bonferroni comparisons revealed that scores from the posttest were significantly higher ($p < .001$ for both) than those from pretest 1 and pretest 2.

The main effect can be explained by the treatment group as their scores were significantly higher in the posttest than in pretest 1 ($t[29] = –2.76, p = .01, d = .60$) or pretest 2 ($t[29] = –2.76, p = .01, d = .58$). No significant changes occurred across administrations by the comparison group. Scores on the Metacognitive Awareness Inventory for the comparison group showed stability over time as indicated by consistent significant correlations between pretest 1 and pretest

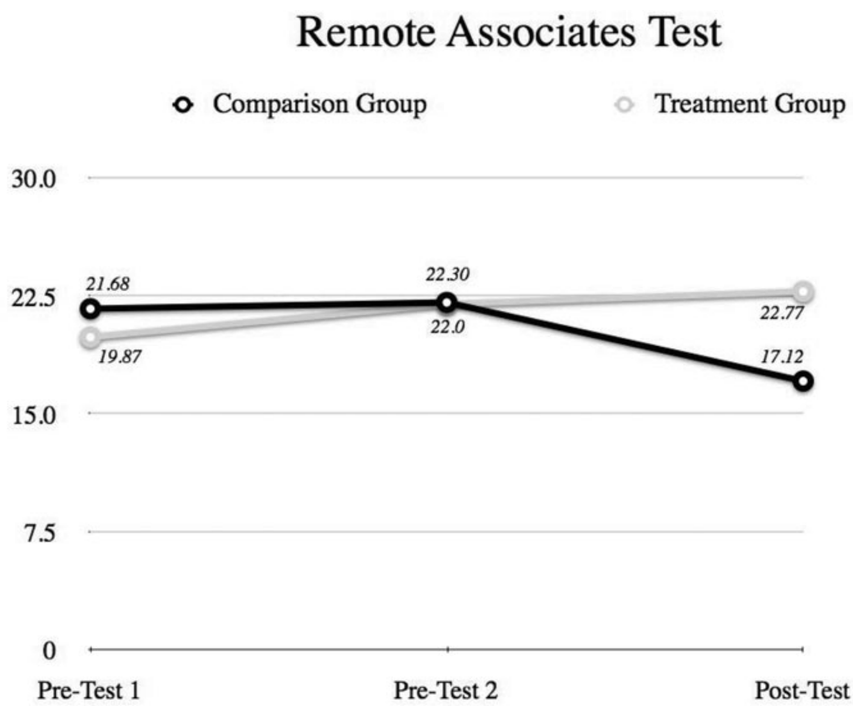

FIGURE 5 Remote associates test results.

2 ($r = .73$, $p < .01$), pretest 1 and posttest ($r = .66$, $p < .01$), and pretest 2 and the posttest ($r = .81$, $p < .01$). However, for students in the treatment group, stability occurred only between the two pretest sessions ($r = .73$, $p < .01$). These findings suggest that the Design Thinking Explorations course had an effect on the posttest Metacognitive Awareness Inventory responses.

What Is the Relation Between Creativity Scores and Self-Report Metacognition?

The correlational statistics provided in Table 4 revealed no significant correlations between the Metacognitive Awareness Inventory and any of the three creativity measures (fluency, originality, Remote Associates Test) for either the treatment or comparison group. Moreover, this lack of relations held across all three administrations of the tests including the posttest for the treatment group. Thus, it appears that, even in the context of extended metacognitive training, self-report metacognitive awareness was not related to these particular aspects of creativity in this sample.

DISCUSSION

Metacognitive skills are critical to effective learning and self-regulation. When developed, these skills can increase the conditional understanding and flexibility required in complex problem solving. Findings in the present study should be considered within the context of design limitations (e.g., treatment participants knowingly participating in a supplementary course) but suggest that creative problem solving can be enhanced with educational interventions that support metacognitive strategy instruction and regulation. Results revealed that undergraduates in the intervention condition outperformed their peers in a comparison condition on measures of associative thinking that included the Similarities Test and Remote Associates Test as well as a domain-specific measure of design thinking processes. This supports prior research claiming that creative thinking can be learned and developed over time (Adams, 2001; Lizarraga et al., 2009; Ritter et al., 2012; Scott et al., 2004; Sternberg & Lubart, 1996). Furthermore, the present findings extend the growing body of literature supporting the efficacy for metacognitive instructional training to positively affect important academic outcomes (Delclos & Harrington, 1991; Desoete et al., 2003; Hacker et al., 2000; Harris et al., 2009; Nietfeld et al., 2006; Pressley et al., 2006). Implications that arise from these findings include the importance of implementing similar pedagogical approaches and also on the measurement and conceptualization of metacognitive skills.

Our findings lend support for the inclusion of formalized training in metacognitive approaches that encourage creative problem solving, and more specifically associative thinking, in ecologically valid contexts. The large effect size differences found in the present study indicate the need for follow-up replication studies using fully randomized control designs. In the present study, an active attempt was made to avoid typical limitations inherent in measuring creativity only with tests of divergent thinking (Zeng et al., 2011). Students who participated in the educational intervention were also found to have significantly higher metacognitive thinking skills represented in their design thought models. This is an important result because the design thought model is a physical manifestation of one's thinking process in a particular domain and evidence of movement from mini-c to little-c on the creativity developmental continuum (Beghetto & Kaufman, 2007).

The intervention in this study was successful for a number of reasons related to the structure of the curriculum itself, which emphasized the development of a conditional understanding of strategy use and incremental development of students' mental models for metacognitive thinking processes (Schraw & Moshman, 1995). Although not a measured outcome, the goal of the educational intervention was to increase students' awareness and appreciation of metacognitive and creative thinking skills. Subsequently, most activities in the Design Thinking Explorations course focused on understanding the importance of process and made clear that the best way to generate creative solutions is to build knowledge of creative thinking strategies and to then use monitoring and control processes in the application of such strategies. Therefore, when presented with an opportunity to exercise these creative strategies in a testing situation, students were more prepared to implement various strategies. In addition, students were asked to reflect on and track their personal mental model development ranging from tacit to formal models (Schraw & Moshman, 1995). This was combined with process-oriented self-assessment that included students making distributed judgments about their placement and growth on the modified Wiggins and McTighe (2005) metacognitive mental model matrix. We would not suggest that the intervention resulted in all students having a fully developed formal model of metacognitive thinking but, rather that the intentional act of reflecting on personal theories over time appeared to positively benefit students' ability to implement their metacognitive skills when provided with the opportunity.

An interesting finding in the present study was the positive correlation between the fluency and originality scores on the Similarities Test. This suggested that in order to generate truly innovative and unique solutions to creative problems, a person must first generate numerous alternatives. It was not typically the case that a student was able to generate a large number of original responses without also generating a large number of alternative responses. An examination of responses coded as original revealed that they tended to occur later in students' lists of alternatives. By generating numerous alternatives, students were able to consider infinitely greater possibilities of how these common responses could be combined, modified, or juxtaposed to generate new responses that were unique. In the process of generating alternatives, a person evokes many common responses that are reflexive, and this likely frees the mind to consider how these common responses may lead to new responses; as such, a new way of looking at the available information occupying the problem state was required. This process illustrates the associationistic approach to creativity adopted in this study (Koestler, 1964; Maltzman, 1960; Mednick, 1962; Ribot, 1900; Spearman, 1931; Wallach & Kogan, 1965).

Findings in the present investigation also lend support for using caution when relying solely on self-report measures of metacognition. Students in the treatment group received higher metacognitive ratings from the neutral judges on the design thought model; however, self-reported findings from the Metacognitive Awareness Inventory did not correlate with the judges' ratings or with the creativity test results. Moreover, students in the treatment condition, but not those in the comparison condition, showed a significant increase in metacognitive awareness on the posttest. Thus, it is possible that students in the treatment condition had higher metacognitive awareness scores as a result of the discussion of metacognitive strategies during the intervention; however, these group gains failed to correspond with the associative thinking posttests or design thought model scores. Regardless of the overall mean increase in scores, one might also reasonably expect the intervention to have encouraged a toggling of scores with some increasing and others decreasing over the course of the semester to correct for initial overconfidence or underconfidence rather than an overall gain across students (as was the case here). However, this still does not explain the lack of match between metacognitive knowledge and the application of metacognitive strategies within the problem-solving tasks. These findings highlight the potential limitations inherent with self-report measures (Winne, 2010) in that participants are either not able or willing to report accurate judgments. A likely conclusion given our findings and previous research is that important relations exist between the constructs of metacognition and creativity but that specific measurement instruments, namely the Metacognitive Awareness Inventory, are not always sensitive enough to reveal these relationships. The primary outcome measures of interest in this study were those related to associative thinking and not metacognition; however, future investigations that use explicit metacognitive training should consider using multiple measures of metacognition rather than relying solely on self-report measures as a form of triangulation in measurement.

Future Directions

Future studies might consider collaboration-based designs (Hadwin, Järvelä, & Miller, 2011; Iiskala, Vauras, Lehtinen, & Salonen, 2011), given that students in the present study appeared to become more active and expressive after participating in such activities. The exercise of students reporting their use of creative strategies is a good example. Asking students to report to one another in groups allowed them to reflect on their own practice and to learn from others' experiences. Open discussion was encouraged, and the sharing of experiences and knowledge was valued.

This study applied a general, relatively domain-independent approach in that content from the larger course (Design Thinking) was not taught or used in practice activities in the Design Thinking Explorations course. An interesting avenue for future research would be to examine a more fully integrated, domain-specific, and highly contextualized focus in a particular content area. Prior research in strategy instruction (Bruning, Schraw, & Norby, 2011) would suggest findings to show larger effects when integrated fully within the curriculum. Systematic comparisons of designs emphasizing interventions that vary on the contextual/decontextual continuum should be considered. Such studies might be useful in informing pedagogical approaches emphasizing the integration of creative and metacognitive approaches in formal educational settings. One approach might be to offer a course similar to the one in the present study that integrates creativity thinking strategies with a metacognitive instructional approach for all first-year students followed by an explicit integration of such processes within advanced discipline specific courses as students' progress in their education.

The Design Thinking Explorations course in the present study was independent of students' design studio and any involvement between the two was voluntary in terms of student participation. Students were encouraged to use what was learned and practiced in the educational intervention during studio; however, this was not a part of the studio instruction or teaching approach. Although this educational intervention was an important first step toward the realization of incorporating this content across the design curriculum, the fact that interaction, discussion, and extended support was limited to the classroom and not in the studio setting serves as a major limiting factor in the advancement of the study and its results. The content introduced and advanced in the educational intervention should be considered for implementation across the curriculum and throughout students' educational experiences in their major field of study (Bruning et al., 2011).

Last, future research could expand on the study to examine other aspects of creativity as it applies to design and also with similar metacognitive interventions in other disciplines. An important question for higher education going forward will be how to restructure courses and programs to ensure that advanced knowledge acquisition is taking place (Spiro, Coulson, Feltovich, & Anderson, 1988).

Limitations

One particular concern is the fact that students in the treatment group participating in the Design Thinking Explorations course were simultaneously engaged with their peers in the larger Design Thinking course. Therefore, students in the treatment group were more likely to be motivated to enhance their thinking processes as a result of their participation in the intervention. Future investigations should consider designs in which the participants themselves are blind to their instructional context relative to other comparison groups. In the case of the present study, we were limited in this regard by our attempt to sample from an externally valid context (i.e., actual college classrooms).

In this study, freshman design students served as the study population. Therefore, the results and conclusions are limited to some degree to this level of education. Future research should assess whether findings generalize across educational levels. Moreover, this study relied on the students' motivation and willingness to explore these strategies on their own. Students who are less motivated or possibly less self-regulated may be more challenged in a similar educational environment. In addition, as with similar designs that select out students for specialized training, we could not account for variations in motivation to perform on tests of creativity because of their selection to the treatment group. Variation in the motivation of students to perform on researcher-presented tests is pervasive in research designs but one that is important to consider and not dismiss. Another limitation of the present study was the inability to reveal relations between metacognition and creativity given that our only measure of domain-general metacognition was the self-reported Metacognitive Awareness Inventory. Other measures of metacognitive thinking and process-related changes could have been developed and included as part of the intervention. Last, our design was not sensitive enough to capture the separate effects of metacognitive instructional approaches or creative thinking strategies because we intended to present the two as an integrated approach. Future research might consider investigating these effects or in systematically varying the level or type of metacognitive instruction or strategy use that is used.

AUTHOR NOTES

Ryan A. Hargrove, Ph.D., is an Associate Professor in the Landscape Architecture department at the University of Kentucky. He received his doctoral degree in design from North Carolina State University and conducted research in design education, examining how to enhance the creative thinking of design students. Dr. Hargrove is currently continuing several research projects on creative thinking and his most recent findings have led to the creation of a course that is being implemented as a general education requirement at the University of Kentucky. Ryan teaches various design studios as well as the creative thinking course entitled Living on the Right Side of the Brain. His future research involves the development of innovative teaching methods. This area of research encompasses design pedagogy, creative thinking, metacognition, and technology.
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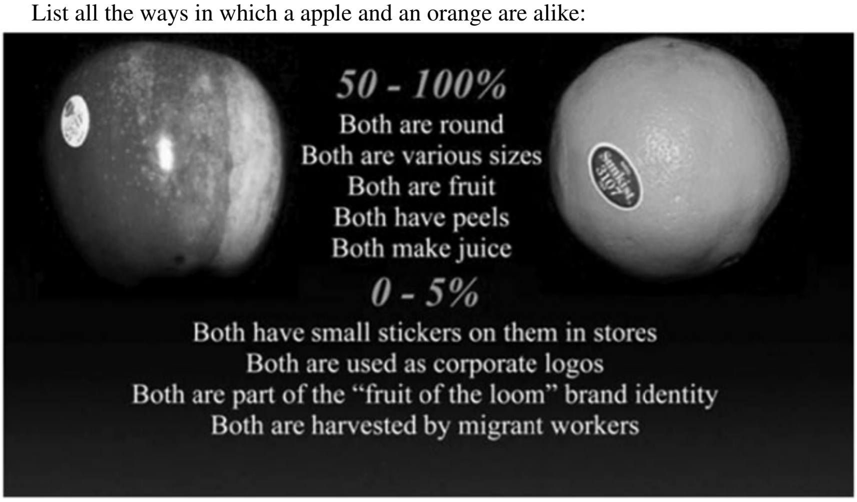
APPENDIX A

Sample Similarities Problem

List all the ways in which a apple and an orange are alike:



APPENDIX B

A Three-Part Presentation

Physical – Design Thought Model

You are asked to create a physical representation of your creative thought process. The final project should not exceed thirty (30) inches in any dimension. A variance is possible with the permission of the course instructor. The model may be made of any nontoxic material.

Written – Critical Manifesto

You will supplement the physical artifact representing your design thought process with a written narrative. This is the final expression of the Critical Manifesto assignment. In this assignment you are asked to practice the act of "thinking about thinking". In order to clearly articulate the cognitive processes (strategies and skills) that make up your creative process, this exercise will serve to strengthen your physical representation by clarifying your intention. The written documentation should include within it at least two (2) photographs of the model.

Verbal – Final Presentation

There will be a required exhibit of the final project for the general review of class members, the course instructor, teaching assistants and invited guests from outside the university. You will be asked to verbally express the operations and meaning expressed in both your written and physical representations. Each student will communicate their process to a sequence of jurors in one-on-one presentations. The goal is to clearly convey your understanding of your own creative thinking process.

APPENDIX C

Schedule for the Semester

Class 1	Activity
	Introduction to creative strategies
	Discussion of class purpose and objectives
Class 2	Creative Strategy 1 – Brainstorming/Reverse Brainstorming
	Framework for effective metacognitive practices
Class 3	Creative Strategy 2 – Lateral Thinking
	Knowledge of cognition
Class 4	Creative Strategy 3 – Random Input
	Regulation of cognition
Class 5	Creative Strategy 4 – Analogy Technique/Forced Analogy/Mind Mapping
	Cycle of knowledge and regulation of cognition
Class 6	Creative Strategy 5 – Metaphorical Thinking
	Key operations of metacognition
Class 7	Creative Strategy 6 – Synectics
	Importance of practice
Class 8	Creative Strategy 7 – The Discontinuity Principle
	Reaching the conceptual level
Class 9	Creative Strategy 8 – Storyboarding
	Rubric for self-assessment
	SELF-ASSESSMENT
Class 10	Creative Strategy 9 – Lotus Blossom Technique
	Metacognitive Facet 1 - Explanation
Class 11	Creative Strategy 10 – Assumption Smashing
	Metacognitive Facet 2 - Interpretation
Class 12	Creative Strategy 11 – Escapism Technique
	Metacognitive Facet 3 - Application
Class 13	Creative Strategy 12 – Search and Reapply Technique
	Metacognitive Facet 4 - Perspective
Class 14	Creative Strategy 13 – Idea Checklist/SCAMPER
	Metacognitive Facet 5 - Empathy
Class 15	Creative Strategy 14 – Attribute Listing/Morphological Charts/Morphological Forced Connections
Class 16	Metacognitive Facet 6 – Self-Knowledge
	Conclusion and Wrap-up