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DEVELOPMENT ARTICLE

Integrating visible thinking and design thinking strategies to improve creativity and growth mindsets

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Abstract
Visible thinking and design thinking are two approaches that have drawn attention. This study integrated these approaches into the teaching of creativity, by which we developed and evaluated the effects of "Making Creative Thinking Visible" (MCTV) on the learning of creativity and creativity mindsets among college students. Five course modules (Introduction, Reset mindset, Unfold mind, Stimulate mind, and Cocreation and reflection) and nine thinking routines of visible thinking were included in the MCTV. The participants were 99 college students, with 54 students receiving the MCTV (the experimental group) and 45 students not receiving any training (the control group). The results suggest that the 12-week MCTV is effective in improving college students' creativity and growth mindsets (both the growth-internal control and the growth-external control mindsets) but not in decreasing fixed mindsets. Additionally, reflections on self-changes during the training show the participants' cognitive transition and the critical components for the success of MCTV. Altogether, the findings of this study provide enlightening thoughts for related educational training and implications for further research.

Keywords Creativity · Growth mindset · Visible thinking · Design thinking

Introduction

With advances in computer technologies and artificial intelligence, creativity has become more critical than ever in our ever-changing society. The Organization for Economic Co-operation and Development (OECD) claims in the *Future of Education and Skills 2030 Project* that creative thinking is a required capability for new and emerging occupations (Organization for Economic Co-operation and Development, 2019). To prepare college students for future challenges, it is essential to foster their ability and beliefs in creativity in higher education.

Creative thinking refers to the process of developing original and valuable ideas or products (Yeh, 2017). A great number of studies have shown that creative thinking can be improved through various types of training, such as incorporating brainstorming (Haase et al., 2023; Rawlinson, 2017), metacognitive instruction (Benedek & Lebuda,

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2024; Hargrove & Nietfeld, 2015), project-based learning (Chen et al., 2022), game-based learning (Yeh et al., 2023), mindful learning through smartphones (Yeh et al., 2020a), SCAMPER (Substitution, Combination, Adaptation, Modification, Putting to other uses, Elimination, and Rearrangement) (e.g., Boonpracha, 2023; Ozyaprak, 2016; Wu & Wu, 2020) and meditation (Haase et al., 2023). Notably, it has been found that the mindsets of creativity are critical to the performance of creative thinking, and growth mindsets of creativity can be enhanced through well-designed training (Yeh et al., 2022, 2023; Zhao et al., 2023). Creativity growth mindsets refer to the belief in the improvement of creativity through learning (Hass et al., 2016; Karwowski, 2014; Liu et al., 2024).

Recently, the teaching approach—*visible thinking*—proposed by Harvard Project Zero has received great attention. Visible thinking is a flexible and systematic research-based conceptual framework that was first proposed to develop a research-based approach to teaching thinking dispositions. The approach emphasized three core practices: thinking routines, the documentation of thinking, and reflective professional practice (Project Zero, 2022). Although visible thinking has been suggested as an effective strategy for promoting creative thinking and creative growth mindsets (Papalazarou, 2015), no empirical quantitative studies have been conducted to examine its effect on creative growth mindsets, and only a few studies have examined its effects on creative thinking (e.g., Mardell et al., 2012; Wilson et al., 2016).

Design thinking is a human-centered problem-solving approach that is usually employed in product design. Its processes include five stages: empathize, define, ideate, prototype, and test (Kelly, 2016). Past studies have found that design thinking enables individuals to generate more creative ideas (Saggar et al., 2017) and fosters creative confidence and mindsets (Kijima et al., 2021). To date, no study has combined visible thinking routines and design thinking to enhance creative thinking and creativity growth mindsets. We believe that these two teaching approaches are complementary and can be combined to maximize such learning effects. Accordingly, we tried to integrate strategies of visible thinking, design thinking, creative thinking, and growth mindsets to develop the training course "Making Creative Thinking Visible" (MCTV), by which we sought to enhance college students' creative thinking and creative growth mindsets in this study.

Theoretical framework

Creativity and creative mindsets

Creativity involves producing appropriate solutions or ideas or creating something novel and valuable. It results from the interplay between personal and environmental factors (Plucker et al., 2004; Yeh, 2017; Yeh et al., 2020b). According to Sternberg and Lubart (1991), creativity results from combining and using six resources, including intellectual processes, knowledge, intellectual style, personality, motivation, and environmental context. Similarly, Seelig (2012) claims that six elements are required for creative thinking: knowledge, imagination, attitude, resources, culture, and habitat. Notably, it is suggested that personality traits are the most influential factor in creative performance (Yeh et al., 2014). Therefore, how to provide a supportive environment to foster the personality traits of creativity is critical to the development of creativity. Among the influential personality traits, creative mindsets have become a recent focus of related research. A creativity

mindset is a motivation-related trait that is viewed as one of the most influential factors for creativity performance (Valgeirsdottir & Onarheim, 2017; Yeh, 2017).

Creativity mindsets, derived from implicit theory (Dweck, 2006), refer to how people perceive their own creative ability (Karwowski, 2014). People with a growth creativity mindset believe that their creative ability can be developed through training or practice (Hass et al., 2016; Karwowski, 2014; Liu et al., 2024). They also tend to see the challenges as opportunities to increase their competence. In contrast, people with a fixed creativity mindset believe creativity is inherent and unchangeable regardless of the time and effort they put in (Hass et al., 2016; Karwowski, 2014; King, 2012; Yeh et al., 2022, 2023). It was found that the growth mindset was positively related to effectiveness in creative thinking, whereas the fixed mindset was negatively associated with interest in creativity and problem-solving, regardless of the cultural influences among the participants (O'Connor et al., 2013). Moreover, it was found that people with a growth mindset have more confidence in viewing their creative ability in comparison with people with a fixed mindset (Karwowski, 2014; O'Connor et al., 2013). Karwowski further stated that perhaps low-growth mindset and low-fixed mindset participants do not care about what creativity is when facing challenges or attempting to solve problems.

Recently, Yeh et al. (2022, 2023) further identified two types of mindsets within the growth mindset and the fixed mindset. Specifically, they proposed four types of creative mindsets: (1) The growth-internal control mindset (GI) refers to the belief that creativity can be improved through self-learning. (2) The growth-external control mindset (GE) refers to the belief that creativity can be improved under suitable learning environments or through others' help control. (3) The fixed-internal control mindset (FI) refers to the belief that creativity is an inherent and unchangeable ability through self-learning control. (4) The fixed-external control mindset (FE) refers to the belief that creativity cannot be improved even under proper learning environments or through others' help. In a game-based learning study, Yeh et al. (2023) found that growth CM, especially GI, is a powerful predictor of self-efficacy of creativity. They suggested that growth mindsets of creativity can be enhanced through a well-scaffolded educational game. In the same vein, Yeh et al. (2022) found that students' GE was improved through story-based creativity games. These results indicate that an individual's creative mindset can be significantly improved. However, no study has employed visible thinking training to enhance a creative mindset.

For the measurement of creativity, divergent thinking (DT) tests have been the most commonly used instrument. A divergent thinking test usually allows individuals to make multiple responses according to a particular prompt. Scoring methods for divergent thinking tests have been a research focus in the field of creativity (Acar & Runco, 2019). Cropley (2000) suggested that assessments of creativity should use multiple tests instead of a single score based on the multidimensional creativity concept. In the past, divergent thinking tests were often scored using four indices. Fluency refers to the total number of responses generated, while flexibility measures the variety of categories produced. Originality assesses the rarity of the responses, and elaboration evaluates their complexity (Dygert & Jarosz, 2020). This study will employ these scoring indices to measure participants' creativity.

Incorporating visible thinking and design thinking into the learning of creativity and creative mindsets

Previous studies (Yeh et al., 2022, 2023) have developed creative thinking programs that incorporate different strategies and have found beneficial impacts on individuals' learning

of creativity and related personality traits. These studies suggest that a digital learning system incorporating comprehensive creative skills and dispositions can foster creative growth mindsets. Additionally, researchers found that mastery experiences play a key role in developing these mindsets (Yeh et al., 2022). Therefore, while individuals acquire the ability to think creatively, their growth mindsets are strengthened as well. Additionally, they found that the following strategies contribute to the enhancement of creativity: positive thinking and attitudes, thinking outside the box and reverse thinking, sensitivity in observation, convergent thinking, lateral thinking, divergent thinking, SCAMPER (i.e., substitution, combination, adaptation, modification, putting to other uses, elimination, and reversing), mind mapping, and creative product design. In the same vein, it has been suggested that multimedia employment, design thinking, web-based instruction, mind mapping strategy, metacognitive instruction, and brainstorming help improve creativity (Bulut, 2019; Hargrove & Nietfeld, 2015; Kuo et al., 2021; Lin & Wu, 2016; Rosba et al., 2021; Suchyadi et al., 2020; Yeh et al., 2019). These strategies were incorporated into strategies of visible thinking and design thinking in our original training course to enhance creativity and growth mindsets.

On the other hand, some researchers have suggested that teaching concepts of neuroplasticity or brain plasticity alters how students think (Dweck, 2012; Paunesku, 2013; Yeager & Dweck, 2012). Early growth mindset interventions (Aronson et al., 2002; Blackwell et al., 2007; Good et al., 2003) also revealed the positive effects of teaching neuroplasticity on cultivating growth mindsets. For example, Aronson et al. (2002) taught college students the concept of a growth mindset and the malleability of the brain—brain networks become "stronger" and more efficient when people keep learning new things and taking on challenges. The results showed that the students reported greater enjoyment of the academic process and greater academic engagement, and obtained higher grade point averages than their counterparts in the two control groups.

Among the creative thinking strategies, design thinking is highly recommended for creative product design. Brought to the mainstream by the global design company IDEO, design thinking has become a flourishing human-centered design concept. Brown (2008) suggests that design thinking involves three phases: inspiration, ideation, and implementation. Design projects must progress through these phases and often cycle back through them as part of the process. The Hasso Plattner Institute of Design at Stanford proposes a 5-step design thinking process: empathize, define, ideate, prototype, and test. This 5-step design process is a cycle in which repeated revisions are made to produce a more accessible product to consumers (IDEO, 2022). In this study, we adapt the IDEO's first four steps for testing the product in the final step, which requires more time and economic support. The adoption of design thinking to facilitate creativity has flourished over the past two decades. Many studies have viewed design thinking as an effective and valuable method of creative problem-solving (Liedtka et al., 2013; Pressman, 2018; Wolcott et al., 2021). According to Liedtka et al. (2013), design thinking presents a fabulous start to fostering creative problem-solving by bringing a systematic end-to-end process to the innovation challenge. Similarly, Pressman (2018) stated that when an individual acquires design thinking, problems begin to look like design problems, and one has the potential to solve the problems creatively. These results suggest that design thinking contributes to the development of creativity. However, no studies have yet examined its impact on the development of creativity mindsets.

Developed from Project Zero at Harvard University, visual thinking is a viable and systematic conceptual framework for teaching and assessment. It has been found that visible thinking strategies can be adopted in computer learning to enhance learners' computational thinking skills by transforming the abstract thinking process into a visible thinking process

(Zhao et al., 2022). Ritchhart and his colleague provide two primary practical strategies for making thinking visible, including asking questions and thinking routines. Asking open-ended and constructive questions helps students think more profoundly. Thinking routines are for introducing and exploring ideas, synthesizing and organizing ideas, and digging deeper into ideas (Papalazarou, 2015; Ritchhart et al., 2011). Thinking routines can be viewed from three perspectives: as a tool, as a framework, and as a behavioral model (Ritchhart et al., 2011). This study employed three categories of thinking routines. The first category includes routines for introducing and exploring ideas from different perspectives, such as see-think-imagine, see-think-wonder, see-think-connect, and compass points. The second category focuses on synthesizing and organizing ideas, utilizing routines like connect-extend-challenge, list-categorize-connect-explain, and "I used to think, but now I think." The third category consists of routines for delving deeper into ideas, including what makes you say that and circle of viewpoints (Papalazarou, 2015; Ritchhart et al., 2011). By integrating these visible thinking strategies into the teaching of creativity, we can realize not only what students think but also understand how they think.

To date, no study has examined the effects of a comprehensive application of "visible thinking routines" on the learning of creativity through quantitative studies, although a few qualitative studies have emphasized the concept of making thinking visible. For example, Mardell et al. (2012) conducted a student-led study of 5-year-old children who were guided to create a video representing what they and their classmates learned. Together with the use of documentation (video, teachers' notes, and children's work) as a way to make children's learning visible to them, the teachers found improvements in the children's creative thinking. In the same vein, Wilson et al. (2016) conducted a study among undergraduate college students in a scientific research class through blogging with question prompts. They asked students to keep their reflection-for-action journal blogs by standing back from their experiences and reflecting on their data, methods, and the research process overall. Their findings showed that blogging methods help record the moments when they think creatively and how their thinking changes.

In conclusion, fostering creativity mindsets is essential for the development of creativity. While growth mindsets—both internal and external—can positively influence creativity, fixed mindsets, whether internal or external, may hinder it. Therefore, it is crucial to examine these mindsets separately. Furthermore, based on the definitions of creativity and related findings, effective creativity training can incorporate practices such as product design and design thinking. Since enhancing creativity and fostering growth mindsets involves complex cognitive processes, these changes take time to manifest. As a result, a comprehensive set of strategies is needed to support this development. Research suggests that thinking routines, design thinking, and holistic thinking strategies contribute to improving creativity and mindsets. Accordingly, we believe that integrating these approaches into a well-designed program can create synergistic effects, enhancing both creative mindsets and overall creativity.

The present study

In this study, we integrated effective strategies for creativity, growth mindsets, and design thinking with visible thinking routines. We used *Canvas by Instructure* (short for Canvas later) learning management system to deliver the training. Additionally, we employed Web 2.0 tools such as mind mapping, and photo blogging to facilitate students' creative learning and practice. By integrating theories, empirical findings, and technology resources,

we developed the training course “Making Creative Thinking Visible” (MCTV). Through MCTV, we examined its effects on college students’ learning of creativity and creativity mindsets. Regarding creativity mindsets, growth mindsets, and fixed mindsets were included. The following three hypotheses were proposed:

- College students who received the MCTV would improve their creativity after the training, whereas those who did not receive the MCTV would not have such an improvement.
- College students who received the MCTV would level up their creativity growth mindsets after the training, whereas those who did not receive the MCTV would not experience such a change.
- College students who received the MCTV would level down their creativity fixed mindsets after the training, whereas those who did not receive the MCTV would not have such a change.

Method

Participants

This study utilized a non-randomized pretest–posttest control group design. Initially, we recruited 127 college students. However, since some participants did not complete either the pretest or posttest, the final sample consisted of 54 valid participants in the experimental group (24 males and 30 females). These participants were enrolled as a cohort in the general education course "Creative Thinking," which is an elective available to all undergraduates at the university where the study was conducted. The control group consisted of 44 valid participants (9 males and 35 females), recruited through a campus online advertisement. Written informed consent was obtained from all participants. While the control group was rewarded with a gift card of approximately 10 USD for taking the pretest and the posttest, the experimental group was rewarded with a gift card of approximately 10 USD.

Instruments

Creativity task

A short version of the Ambiguous-photo Imagination Test (AIT) (Yeh, 2020), which is a divergent thinking test, was employed in this study to measure participants’ creativity. The AIT includes ten test items of ambiguous black-and-white photos, in which participants were requested to think of as many original answers as possible (see Fig. 1 for examples). With a test time of 1 min for each test item, the AIT took 10 min to complete. The AIT measured four indices: fluency, flexibility, originality, and elaboration. The Cronbach’s α coefficients for the indices ranged between .90 and .94. Moreover, the item analysis results showed that all test items had good discriminate validity (Yeh, 2020).

The AIT Fluency refers to the number of ideas the participants come up with, with each valid answer scored as 1 point. Flexibility refers to cross-category thinking. For example, answers within the same category were scored as 1 point, and those across three categories were scored as 3 points. Originality refers to the novelty (i.e., percentage) of answers. The

Fig. 1 Examples of the AIT

scoring criteria were defined as follows: 0 points for responses of 16% or more, 1 point for responses between 5 and 16%, 2 points for responses between 2 and 5%, and 3 points for responses below 2%. Additionally, the elaboration score was based on the complexity of the descriptions for each test item, with the following scale: 0 points for an incomprehensible answer, 1 point for a description using a simple noun, 2 points for a description using an adjective, 3 points for a description using compound adjectives, and 4 points for a description that includes vivid situations. The total AIT score was the average T-score of the four scoring indices. Based on the sample of this study, Cronbach's α coefficients were .967, .934, .967, and .876 for the four indices, respectively.

Creativity mindset inventory (CMI)

The CMI was employed to measure participants' creativity mindsets. The CMI is a 6-point Likert-type scale ranging from 1 to 6 points, representing "strongly disagree" to "strongly agree." With 12 items, the CMI included four factors: growth-internal control (GI), growth-external control (GE), fixed-internal control (FI), and fixed-external control (FE) (Yeh et al., 2023). Based on the current sample, the Cronbach's α coefficients for GI, and GE were .779, and .880, respectively. The Cronbach's α for the, FI, and FE were .854, and .898, respectively.

Furthermore, the results of confirmatory factor analysis revealed that the four-factor model had good construct validity and reliability: χ^2 ($df = 44$) = 96.646, $p < .001$; the goodness-of-fit index = .899, the adjusted goodness-of-fit index = .821, the root mean square residual = .055, the standardized root mean square residual = .055, and the root mean square error of approximation = .094. In terms of relative fit measures, the normed fit index = .907, the incremental fit index = .947, and the comparative fit index = .946. The composite reliability (ρ_c) values of GI, GE, FI, and FE were .773, .655, .834, and .827, respectively. The average variance extracted (ρ_v) values of the four factors were .534, .397, .630, and .619, respectively. These results suggested that CMI has good reliability and validity (Yeh, 2020).

Experimental design and procedures

This study employed a pretest–posttest control group design. The control group only completed a pretest in the first week and a posttest in the 12th week, while the experimental group also received experimental instruction through a blended-learning course titled

'Creative Thinking". All participants received the pretest of the measurement of creativity and mindsets in the first week. The experimental group received the "Making Creative Thinking Visible" (MCTV) from the first to the 11th week, whereas the control group did not receive such training. In the 12th week, all participants took the posttest. To minimize the risk of biased responses from the experimental group in this study, we informed them, both before enrollment and when completing the measurements, that the creativity-related tests and inventories would not impact their grades and were intended to provide insight into their personal traits and support self-improvement. The MCTV was developed based on the approach of making thinking visible (Ritchhart et al., 2011), design thinking strategies (Kelly, 2016), and the strategies of developing creativity and creativity mindsets (e.g., Yeh et al., 2022, 2023). It was developed to improve college students' creativity, by which the learning effects were examined. Regarding the incorporation of design thinking, we only adopt IDEO's (2022) first four steps (i.e., empathize, define, ideate, and prototype) for the final step (test), which requires more time and economic support. Figure 2 and Table 1 illustrate the procedures and instructional design of this study. In addition to the pretest and the posttest, the experimental instruction includes 5 modules: Introduction, Reset mindset, Unfold Mind, Stimulate mind, and Cocreation and reflection. All experimental instruction was conducted through face-to-face classes supported by the online platform Canvas. Canvas was used to facilitate group discussion results, creativity skill practices, product design, and online observational learning through assignment sharing (see Fig. 3 for examples). The following four assignments were requested during the training: Try at least one thing new for 4 weeks, mind mapping, product design, and "I used to think… Now I think." Examples of product design are shown in Fig. 4.

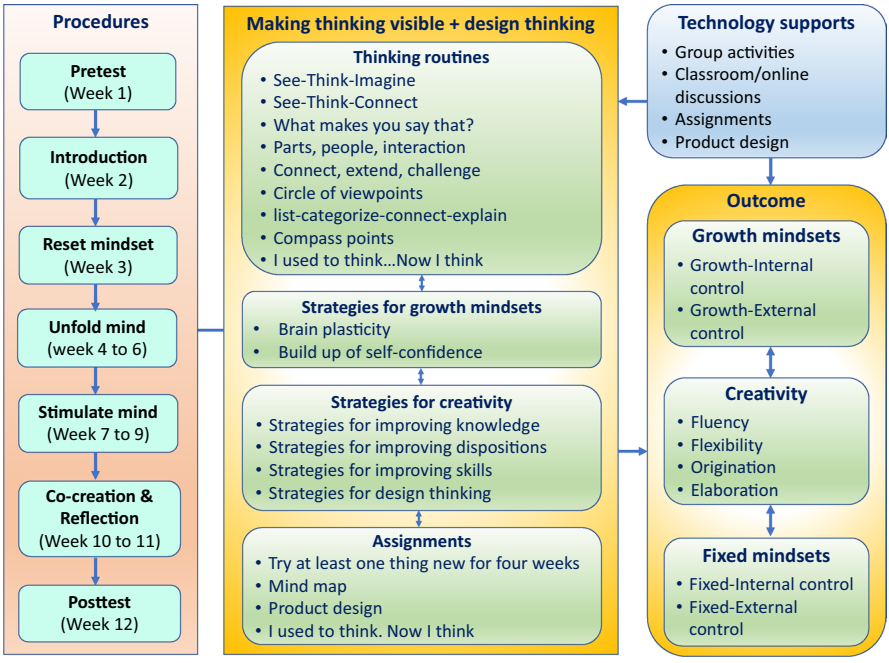

Fig. 2 Instructional design and procedures

Table 1 The content of "making creative thinking visible"

Topic	Course content	Thinking routines (Creative thinking strategies)
Pretest (Week 1)	Self-assessment of creativity and creativity mindsets	
Module #1 Introduction (Week 2)	Introduction to Canvas Introduction, discussion, and practice of creativity	What makes you say that? (Discuss what creative thinking is)
Module #2 Reset your mindset (Week 3)	Discussion of growth mindsets vs. fixed mindsets Practices of growth mindsets Discussion and practice of brain plasticity, imagination, and dispositions of creativity	Parts, people, interaction (The relationship between society and personal creativity) What makes you say that? (Explain ideas)
Module #3 Unfold your mind (Weeks 4–6)	Discussion and practice of idea generation Discussion and practice of strategies for developing knowledge to produce creative ideas and strategies for developing dispositions of creativity	See-Think-Imagine (Black-and-white photo imagination) See-Think-Connect (Color photo imagination) What makes you say that? (Explain ideas) I used to think… Now I think…(Reflect on change in habits)
Module #4 Stimulate your mind (Weeks 7–9)	Discussion and practice of creativity skills, such as observation, imagination, SCAMPER, design thinking, 6 thinking hats, mind mapping, creative stories, etc	See-Think-Imagine (Lateral thinking) Connect, extend, and challenge (SCAMPER and design thinking) What makes you say that? (Explain ideas) Circle of viewpoints (Brainstorming, SCAMPER, and six thinking hats) List-categorize-connect-explain (Mind mapping) Compass points (Design thinking)
Module #5 Cocreation and reflection (Week 10–11)	Presentation and sharing of creative products	I used to think… Now I think…(Reflect on changes through the experimental instruction)
Posttest (Week 12)	Self-evaluation of creativity and creativity mindsets	

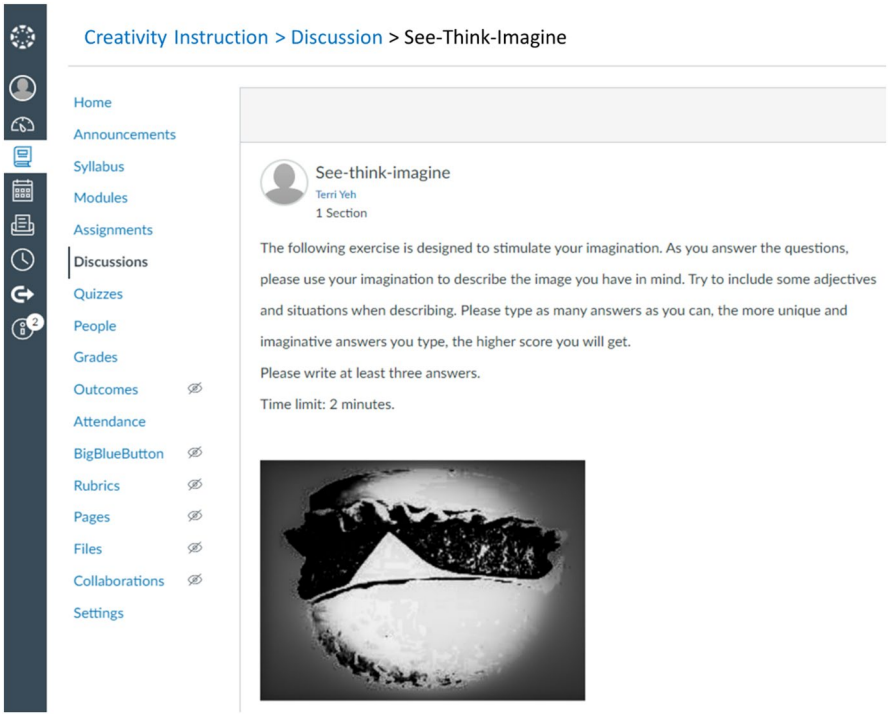

Fig. 3 Exemplifying screenshot of Canvas. The screenshot demonstrates the practice of "See-Think-Imagine" strategy through Canvas. Participants were encouraged to use their imagination to describe the provided photo

The core concepts of the training were *making thinking visible* and *design thinking*. Many thinking routines of visible thinking were incorporated into the teaching strategies for growth mindsets and creativity as well as assignments (see Fig. 2 and Table 1 for details). Notably, design thinking was introduced to help students produce a creative design at the end of the experiment.

Data analyses

This study employed a mixed-methods approach, collecting both quantitative and qualitative data. Quantitative data were analyzed using mixed-design ANOVAs to examine instructional effects. Qualitative data were gathered through the question "I used to think… Now I think" to support and enrich the quantitative findings. For the analysis of qualitative data, we employed quantitative content analysis (Maxwell, 2010; Neale et al., 2014). This approach utilizes quantitative techniques, such as frequency descriptive analysis and frequency counts, to summarize findings from the sample. The first author, with 27 years of experience in teaching and researching creativity, and the second author, a postdoctoral researcher, initially coded the text into an evolving set of concepts, allowing for revisions during the discussion process. After thorough deliberation, they developed a consolidated checklist and proceeded with content analysis, coding for the frequency of each concept.

Fig. 4 Examples of product design—application of design thinking. Participants were assigned group work to develop a creative product using design thinking and present it in class. The two illustrated group projects are "Future Washer" (on the left) and "Pet Translator" (on the right)

Notably, since our participant group had more females than males, we conducted an Independent-samples T-test to examine whether there were gender differences in the pretest scores of creativity and the four types of creativity mindsets. The results showed no significant gender differences in creativity with t values ranging from −2.60 to 1.72 and *p* values ranging from .33 to .74. Moreover, all Levene's *F* values (.046 to .615) were not significant, suggesting the two genders were with equal variance. Therefore, we did not include gender in our analysis of the instructional effects.

Results

Effects of MCTV on creativity improvement

The study employed mixed-design ANOVAs to examine the training effects on creativity improvement, in which one between-group factor *Group* (Experimental vs. Control) and one repeated-measures factor *Time* (pretest vs. posttest of AIT-short) were employed. Means and standard errors are depicted in Fig. 5. In this analysis, due to one missing value in the posttest, the included sample size was 98. Levene's tests for equality of error variances were not significant for both the pretest and posttest ($ps = .877$ and .848), allowing us to proceed with the Scheffé post-hoc test. The results revealed a significant *Time* × *Group* interaction effect on the participants' creativity performance, $F(1, 97) = 4.81$,

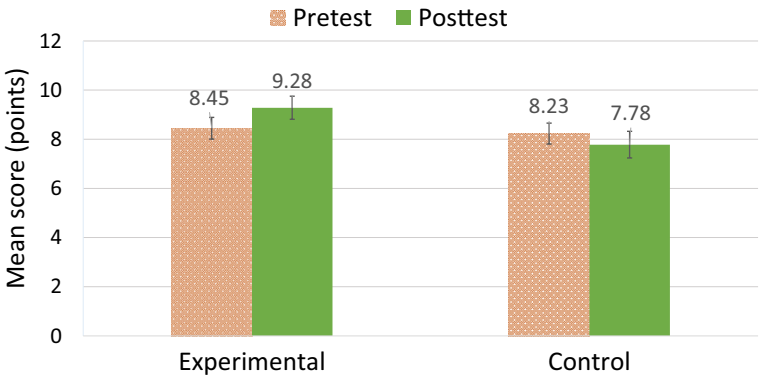

Fig. 5 Ms and SEs of creativity scores for the experimental and the control group

$p = .031$, $\eta_p^2 = .047$. Further analyses of the simple main effect revealed that the experimental group had a higher level of creative performance in the posttest than in the pretest, $F(1, 97) = 4.46$, $p = .037$, $\eta_p^2 = .044$, whereas there was no significant difference in the control group. In contrast, the experimental group had a higher level of creative performance than the control group in the posttest, $F(1, 97) = 4.33$, $p = .040$, $\eta_p^2 = .043$, whereas there was no significant difference in the pretest (see Table 2). These results indicate that MCTV is effective in improving college students' creativity.

Effects of MCTV on creativity mindset improvement

This study employed mixed-design ANOVAs to examine the training effects on creativity mindset improvement, in which one between-group factor *Group* (Experimental vs. Control) and one repeated-measures factor *Time* (pretest vs. posttest of AIT-short) were employed. Means and standard errors are presented in Fig. 6. Regarding creativity growth-internal mindset (GI), Levene's tests for equality of error variances were not significant for both the pretest and posttest (*p*s = .363 and .619), allowing us to proceed with the Scheffé post-hoc test. The results revealed a significant *Time* × *Group* interaction on participants' GI, $F(1, 98) = 23.26$, $p < .001$, $\eta_p^2 = .192$ (see Table 3). Further analyses of the simple main effect revealed that the experimental group had

Table 2 ANOVA of Group and time on creativity performance

Source	ANOVA				Simple main effect
	MS	*F(1, 97)*	*p*	η^2_p	
Time	1.78	.43	.514	.004	*n.s*
Time × Group	19.90	4.81*	.031	.047	E: Posttest > Pretest ($p = .037$) Posttest: E > C ($p = .040$)
Group	36.53	1.85	.177	.019	*n.s*

* $p < .05$. *E:* experimental group, *C:* control group

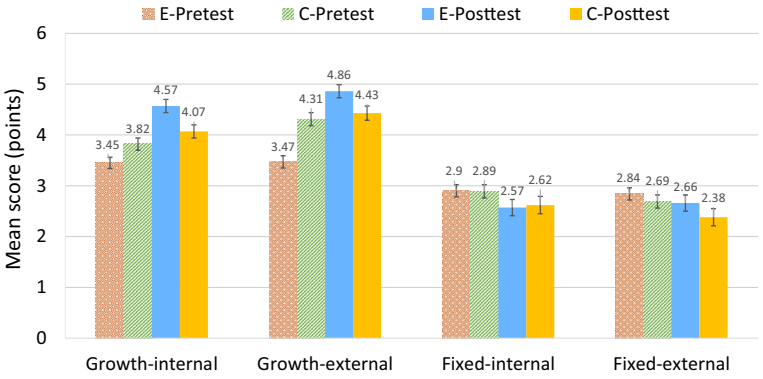

Fig. 6 Ms and SEs of creativity mindsets for the experimental and the control group. *E* experimental group, *C* control group, *GI* growth-internal mindset, *GE* growth-external mindset, *FI* fixed-internal mindset, *FE* fixed-external mindset

Table 3 ANOVA of group and time on creativity mindsets

Source	ANOVA				Post hoc test
	MS	*F*(1,98)	*p*	η^2_p	
Growth-internal control mindset					
Time	23.299	57.312***	.000	.369	Posttest > Pretest ($p < .001$)
Time × Group	9.455	23.257***	.000	.192	E: Posttest > Pretest ($p < .001$) Pretest: C > E ($p = .026$) Posttest: E > C ($p = .008$)
Group	.216	.194	.660	.002	
Growth-external control mindsets					
Time	27.916	57.039***	.000	.368	Posttest > Pretest ($p < .001$)
Time × Group	20.094	41.057***	.000	.295	E: Posttest > Pretest ($p < .001$) Pretest: C > E ($p < 001$) Posttest: E > C ($p = .026$)
Group	2.099	1.811	.182	.018	
Fixed-internal control mindset					
Time	4.526	6.817**	.010	.065	Pretest > Posttet
Time × Group	.051	.076	.783	.001	
Group	.018	.013	.909	.000	
Fixed-external control mindset					
Time	2.882	3.903	.051	.038	*n.s*
Time × Group	.207	.280	.598	.003	
Group	2.260	1.582	.211	.016	

** $p < .01$. *** $p < .001$. *E:* experimental group, *C:* control group

a significantly higher level of GI in the posttest than in the pretest, $F(1, 98) = 81.70$, $p < .001$, $\eta_p^2 = .455$, whereas no significant differences were found in the control group. On the other hand, the control group had a higher level of GI than the experimental group in the pretest, $F(1, 98) = 5.11$, $p = .026$, $\eta_p^2 = .050$, whereas the experimental

group had a higher level of GI than the control group in the posttest, $F(1, 98) = 7.38$, $p = .008$, $\eta_p^2 = .070$ (see Table 3).

As for creativity growth-external mindset (GE), Levene's tests for equality of error variances were not significant for both the pretest and posttest ($ps = .255$ and .778), allowing us to proceed with the Scheffé post-hoc test. The results revealed a significant *Time* × *Group* interaction effect on GE, $F(1, 98) = 41.06$, $p < .001$, $\eta_p^2 = .295$. The result of the simple main effect showed that the experimental group had a higher level of GE in the posttest than in the pretest, $F(1, 98) = 103.66$, $p < .001$, $\eta_p^2 = .514$, whereas no such difference was found in the control group. In contrast, the control group had a higher level of GE than the experimental group in the pretest, $F(1, 98) = 23.38$, $p < .001$, $\eta_p^2 = .193$, whereas the experimental group had a higher level of GE than the control group in the posttest, $F(1, 98) = 5.14$, $p = .026$, $\eta_p^2 = .050$ (see Table 3).

As for creativity fixed-internal mindset (FI), no Time × Group interaction or main effect of Group was found. Only the main effect of Time was significant, $F(1, 98) = 6.817$, $p = .010$, $\eta_p^2 = .065$. Comparisons of means indicated that the participants' overall score of the fixed-internal mindset decreased after the training. Finally, no significant main effect of Time, Group, or Time × Group interaction was found (see Table 3).

Self-reflection on changes

To help participants understand their self-growth, we asked them to reflect on their changes by completing the sentence, "I used to think… Now I think." The participants reflected that they had redefined creativity, improved their creativity (self-growth), and changed their values and habits concerning creativity. They had also become more capable in multi-perspective thinking, expression and sharing, open-mindedness, observation, use of creative skills, and use of creativity enhancement strategies. Additionally, they had become more self-confident and courageous in trying new things. Importantly, they had become more faithful in their creativity growth mindset and more able to enjoy creative thinking activities than before (see Table 4).

Discussion

Creative thinking has become an essential skill for college students to cope with various challenges in the future. Therefore, this study developed a course-based, 11-week training named "Making Creative Thinking Visible" (MCTV) to enhance college students' creativity and facilitate their growth mindsets of creativity. To achieve our goals, we proposed three hypotheses in this study.

Instructional effects of fostering creativity

The first hypothesis was supported. We found that the students' creativity was enhanced after taking the MCTV, whereas students who did not receive the MCTV did not make similar gains. The results suggest that MCTV can enhance college students' creativity and growth mindsets. The findings here are in line with past findings that a well-constructed education program can positively impact students' creative thinking skills (Bulut, 2019; Hargrove & Nietfeld, 2015; Kuo et al., 2021; Lin & Wu, 2016; Rosba et al., 2021; Suchyadi et al., 2020), visible thinking positively impacts college students' learning of creativity

Table 4 Self-reflection on changes through "I used to think… now I think"

Response	count	Example
Changes in creativity mindsets		
Courage of trying	15	I used to set a lot of limits on what I can do and cannot do. Now I do not set such limits before I do something. Instead, I tell myself, "just do it." (G15)
Creativity growth mindset	13	I used to think creativity was innate. Now I think it can be cultivated (G24)
Self-confidence	12	I used to think that I couldn't change the world. Now I know I have a chance (G09)
Change of values	9	I used to think that my ideas must be in line with the values in society and that there is only one right answer to everything. Now I think everything is possible and there is no right answer or best answer (G43)
Change of habits	8	I used to use the same pattern for my daily activities. After taking the class, I now try to brush my teeth with my left hand (nondominant hand) and try to experience new things (G06)
Positive emotion	4	I used to hate brainstorming ideas. Now I enjoy doing this (G16)
Self-growth	3	I used to think about how to just pass a course I took. Now I try my best to record special things that happen in my life or any self-growth. I feel that my creativity has been substantially improved (G18)
Changes in creativity skills		
Multi-perspective thinking	21	I used to think rigidly and would only follow the general rules. Now I can think more diversely than before because of the interaction and idea-sharing with classmates in class (G04)
Redefine creativity	18	Through reflections on homework, I began to pay attention to the actions I took and things that happened in my life. I now find that creativity is not about accomplishing a great thing; finding motivation and having fun in life is also a way to cultivate creativity (G12)
Creativity enhancement	13	I used to limit my creativity by over-considering practicality and feasibility. Now I give full play to my ideas and then think about feasibility, which makes it easier to produce creative ideas (G41)
Use of creative skills	10	I used to throw a product away or find a replacement when I felt it was inconvenient to use it. Now I think about how the product can be improved by using the multi-perspective creative thinking strategies I learned in class to imagine the possibilities of various innovative designs (G38)
Expression and sharing	8	I used to have a hard time finding breakthroughs in my thinking. Now I find that I can find my blind spots by sharing and discussing ideas with others (G25)
Open-mindedness	6	I used to think about things in a more self-centered way. Now I can think in others' shoes (G16)
Sensitivity in observation	5	I used to pay little attention to the things around me. Now I usually pay attention to trivial things around me (G17)

(Wilson et al., 2016), and design thinking facilitates creative problem solving (Liedtka et al., 2013; Pressman, 2018; Wolcott et al., 2021). Additionally, the findings of this study support that computer-supported visual instructional digital tools, such as mind mapping (Guo et al., 2019), photo taking (Yeh et al., 2020a), video, and storyboarding (Mardell et al., 2012), help learners express their creativity. These visual tools were all employed in this study.

Notably, the uniqueness of our MCTV lies in its integration of visible thinking, design thinking, creative thinking, creativity growth-mindset strategies, and technology support. Visible thinking routines enable learners to observe, organize, and document their thoughts, transforming abstract thinking into a more concrete form and allowing them to "see" their thinking processes. This approach, while effective, has not been widely utilized to foster students' creative thinking and growth mindsets. On the other hand, the design thinking approach, which aims to produce creative products, can be complementary to the visible thinking approach for a better learning effect of creativity. Additionally, we used Canvas discussion feature for instant thought-sharing and knowledge creation. Such a comprehensive instructional design helps realize not only what students think but also understand how they think.

In addition to the quantitative evidence that supports MCTV improving students' creativity and growth mindsets, the qualitative data obtained from the participants provide explanations of how MCTV works. From the qualitative responses, we see the participants' transition experiences before and after the training. They become more creative by redefining creativity, thinking outside the box, expressing and sharing ideas to find the blind spots, using more creative skills and strategies, being more sensitive in observation, and being more competent in open-mindedness and multiperspective thinking (see Table 4). For example, Participant G41 stated "I used to limit my creativity by over-considering practicality and feasibility. Now I give full play to my ideas and then think about feasibility, which makes it easier to produce creative ideas." Participant G38 responded "I used to throw a product away or find a replacement when I felt it was inconvenient to use it. Now I think about how the product can be improved by using the multi-perspective creative thinking strategies I learned in class to imagine the possibilities of various innovative designs." These reflections on self-changes in creativity indicate that the components of MCTV are critical for creativity training, which lends support to previous findings (Bulut, 2019; Hargrove & Nietfeld, 2015; Kuo et al., 2021; Lin & Wu, 2016; Rosba et al., 2021; Suchyadi et al., 2020).

Instructional effects of enhancing creative growth mindsets

The results supported the second hypothesis regarding the effectiveness of the MCTV in improving college students' growth mindsets of creativity. Specifically, the results revealed that the experimental group significantly enhanced their growth-internal control mindsets and growth-external control mindsets after completing the MCTV, whereas the control group did not have such improvements. In other words, students strengthened their belief that they can improve their creativity through self-learning, with the help of others and with the proper learning environments after taking the MCTV. The results support the previous findings that the growth mindset of creativity can be developed through proper training or practices (Hass et al., 2016; Karwowski, 2014).

Moreover, the qualitative results demonstrate the details of students' cognitive transition in creativity mindsets before and after the training. Participants enhanced their growth

mindsets by breaking their old patterns of action and initiating new patterns to have new habits, recording their self-growth, and being braver in trying new experiences. In addition, their thoughts changed to the belief that their creative ability and self-confidence could be boosted. They also became more able to enjoy the process of conducting creative thinking. For example, participant G24 stated "I used to think creativity was innate. Now I think it can be cultivated." Participant G15 responded "I used to set a lot of limits on what I can do and cannot do. Now I do not set such limits before I do something. Instead, I tell myself, "just do it." These results are in line with the literature that creativity growth mindsets are strongly associated with creative self-efficacy (Yeh et al., 2023). Additionally, combined with the results concerning the improvement of creativity, the findings suggest that the MCTV can both enhance students' creativity and the growth mindset of creativity. This makes sense because past studies have suggested that creativity growth mindsets are positively related to creativity (Karwowski, 2014) and creative thinking (O'Connor et al., 2013). Since the MCTV was designed to train college students' creative thinking to enhance their creativity, students might also strengthen their growth mindset of creativity while learning creative thinking. Notably, our MCTV also incorporates the instruction and exercises of brain plasticity through videos, class practices, and discussions. The findings of this study support that the instruction of brain plasticity enhances growth mindsets (Blackwell et al., 2007; Dweck, 2012; Good et al., 2003; Paunesku, 2013; Yeager & Dweck, 2012).

Instructional effects of decreasing creative fixed mindsets

Our third hypothesis concerning the decrease in fixed mindsets was not supported. We found that the MCTV did not significantly decrease the participants' fixed-internal control mindset or the fixed-external control mindset. However, the findings indicate a trend of declination in the fixed-internal control mindset in the experimental group. The findings suggested that MCTV may have a better effect on enhancing growth mindsets than decreasing fixed mindsets, and it is difficult to change college students' beliefs that creativity is inherent and unchangeable regardless of their efforts or the resources they receive. Past studies have suggested that fixed mindsets impede an individual's creativity performance (Hass et al., 2016; Karwowski, 2014; King, 2012). This study, however, found that while holding a certain degree of the fixed mindsets of creativity seems inevitable, a strong growth mindset may decrease or eliminate the negative influence of fixed mindsets on creativity performance and, further, enhance creative performance. Additionally, the findings of this study support that people may simultaneously hold fixed and growth mindsets (Hass et al., 2016; Karwowski, 2014). Moreover, the fixed mindset does not have an absolute inverse relationship with the growth mindset. In other words, when one is up, the other may not be down. Accordingly, training that helps increase one's growth mindset of creativity does not guarantee the same effect on decreasing one's fixed mindset, but enhancing growth mindsets is critical to improvements in creativity.

Conclusions

Due to the importance of creativity in this changing and challenging epoch, we pioneered in integrating strategies of visible thinking, design thinking, creative thinking, and growth mindsets to develop the novel and comprehensive course "Making Creative Thinking

Visible" (MCTV), by which we examine its ability to enhance college students' creative thinking and creative growth mindsets, as well as on decreasing their fixed mindsets. Both the quantitative and qualitative results indicate that the MCTV is effective in strengthening college students' creative thinking and creative growth mindsets but not in decreasing their fixed mindsets. Additionally, the qualitative results revealed the students' transition in creative thinking and creativity growth mindsets during the training, which provides an understanding of cognitive processes during such training. The findings of this study, along with the effectiveness of the employed instructional design, offer valuable insights for related educational training and implications for further research. Notably, the innovative training framework provides concrete and practical guidelines for fostering creativity and creative mindsets.

Limitations and implications

The study employed a quasi-experimental design because the course-based training had its constraints, preventing random assignment of students to either the experimental or control group. Nevertheless, the positive results from both qualitative and quantitative data support the effectiveness of the MCTV in enhancing college students' learning of creativity and growth mindsets. Moreover, this study did not measure creativity or relevant personal traits in the middle of the MCTV training. Based on past teaching experiences, administering too many tests would result in negative attitudes about the course. Therefore, we did not examine the dynamic changes in students' creativity or mindsets. Future studies may add discussions during the class to understand the transformation of students' creativity or associated personality traits.

Comparatively, we put more time and emphasis on creativity than creativity mindsets, partly because we postulated that growth mindsets could be indirectly leveled up and fixed mindsets could be indirectly decreased through the improvement of creativity. However, the findings of this study suggest that directly cultivating students' growth mindsets has the potential to enhance their creativity. However, reducing students' fixed mindsets may require more successful experiences to build self-confidence. Future research can incorporate instructional activities that increase successful experiences and directly reinforce the growth mindset. Moreover, instructors can create opportunities for students to reflect on their failures and give them constructive feedback. By framing mistakes as learning opportunities, students can shift away from fixed mindsets and view effort as key to development.

Additionally, this study included more female than male participants. The t-test results indicated no significant gender differences in creativity performance and mindsets, supporting previous findings that biological gender does not significantly influence general creativity performance (Baer & Kaufman, 2011; Betancourt et al., 2022; Taylor & Barbot, 2021) or creative mindsets (Ching et al., 2023). However, while some research suggests that gender can influence creativity (Hora et al., 2022; Kang & Park, 2024), few studies have focused on gender differences in creative mindsets. Due to the small sample size in this study, the influence of gender on creativity and creative mindset requires further verification.

Furthermore, this study integrated the concept of design thinking proposed by (IDEO, 2022) into the training course. However, only the first four steps (i.e., empathize, define, ideate, prototype) were included. The final step—the test—was not included because it requires more time and economic support, and including this step would be beyond the

requirements of a course in general education. Nevertheless, our findings reveal that employing visual thinking while going through design thinking processes inspired students' creative thinking. Instructors may guide students to implement visible thinking routines like "See-Think-Connect" during the empathize phase of design thinking. For example, ask them to observe (See), analyze (Think), and reflect on experiences (Connect) about the perspectives of the users they are designing for.

Finally, the MCTV is a 12-week training program embedded in an undergraduate course. The course design is comprehensive because we believe that enhancing creativity and fostering a creativity mindset requires a set of skills or strategies that take time to practice and internalize. However, if time is limited, researchers or instructors can select one or two thinking routines or creativity strategies for shorter interventions or brief classroom activities. For example, students can practice "See-Think-Imagine" for 5 min multiple times, or they can be guided through a design thinking assignment.

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Data availability Data is available upon request.

References

Acar, S., & Runco, M. A. (2019). Divergent thinking: New methods, recent research, and extended theory. *Psychology of Aesthetics, Creativity, and the Arts, 13*(2), 153. https://doi.org/10.1037/aca0000231

Aronson, J., Fried, C. B., & Good, C. (2002). Reducing the effects of stereotype threat on African American college students by shaping theories of intelligence. *Journal of Experimental Social Psychology, 38*(2), 113–125. https://doi.org/10.1006/jesp.2001.1491

Baer, J., & Kaufman, J. C. (2011). Gender differences in creativity. *Journal of Creative Behavior, 42*(2), 75–105. https://doi.org/10.1002/j.2162-6057.2008.tb01289.x

Benedek, M., & Lebuda, I. (2024). Managing your muse: Exploring three levels of metacognitive control in creative ideation. *Creativity Research Journal*. https://doi.org/10.1080/10400419.2024.2347770

Betancourt, J., Valadez, M. D., Rodríguez-Naveiras, E., Flores, J. F., & Borges, Á. (2022). Differences between creativity and gender in students with high abilities attending a school with total grouping. *Children, 9*(7), 1081. https://doi.org/10.3390/children9071081

Blackwell, L. S., Trzesniewski, K. H., & Dweck, C. S. (2007). Implicit theories of intelligence predict achievement across an adolescent transition: A longitudinal study and an intervention. *Child Development, 78*(1), 246–263. https://doi.org/10.1111/j.1467-8624.2007.00995.x

Boonpracha, J. (2023). SCAMPER for creativity of students' creative idea creation in product design. *Thinking Skills and Creativity, 48*, 101282.

Brown, T. (2008). Design thinking. *Harvard Business Review, 86*(6), 84.

Bulut, B. (2019). The impact of peer instruction on academic achievements and creative thinking skills of college students. *International Journal of Educational Methodology, 5*(3), 503–512. https://doi.org/10.12973/ijem.5.3.503

Chen, S. Y., Lai, C. F., Lai, Y. H., & Su, Y. S. (2022). Effect of project-based learning on development of students' creative thinking. *The International Journal of Electrical Engineering & Education, 59*(3), 232–250. https://doi.org/10.1177/0020720919846808

Ching, B. H., Wu, H. X., & Li, X. F. (2023). Creative mindsets are malleable: Effects of "born this way" messages and different definitions of creativity. *Thinking Skills and Creativity, 48*, 101308. https://doi.org/10.1016/j.tsc.2023.101308

Cropley, A. J. (2000). Defining and measuring creativity: Are creativity tests worth using? *Roeper Review, 23*(2), 72–79. https://doi.org/10.1080/02783190009554069

Dweck, C. S. (2006). *Mindset: The new psychology of success*. Random House.

Dweck, C. S. (2012). Mindsets and human nature: Promoting change in the middle east, the schoolyard, the racial divide, and willpower. *American Psychologist, 67*(8), 614. https://doi.org/10.1037/a0029783

Dygert, S. K., & Jarosz, A. F. (2020). Individual differences in creative cognition. *Journal of Experimental Psychology: General, 149*(7), 1249–1274. https://doi.org/10.1037/xge0000713

Good, C., Aronson, J., & Inzlicht, M. (2003). Improving adolescents' standardized test performance: An intervention to reduce the effects of stereotype threat. *Journal of Applied Developmental Psychology, 24*(6), 645–662. https://doi.org/10.1016/j.appdev.2003.09.002

Hargrove, R. A., & Nietfeld, J. L. (2015). The impact of metacognitive instruction on creative problem solving. *The Journal of Experimental Education, 83*(3), 291–318. https://doi.org/10.1080/00220973.2013.876604

Hass, R. W., Katz-Buonincontro, J., & Reiter-Palmon, R. (2016). Disentangling creative mindsets from creative self-efficacy and creative identity: Do people hold fixed and growth theories of creativity? *Psychology of Aesthetics, Creativity, and the Arts, 10*(4), 436. https://doi.org/10.1037/aca0000081

Haase, J., Hanel, P. H. P., & Gronau, N. (2023). Creativity enhancement methods for adults: A meta-analysis. *Psychology of Aesthetics, Creativity, and the Arts*. https://doi.org/10.1037/aca0000557

Hora, S., Badura, K. L., Lemoine, G. J., & Grijalva, E. (2022). A meta-analytic examination of the gender difference in creative performance. *Journal of Applied Psychology, 107*(11), 1926–1950. https://doi.org/10.1037/apl0000999

IDEO. (2022). Design thinking defined. Retrieved December 1, 2022, from https://designthinking.ideo.com/.

Kang, S., & Park, H.-S. (2024). Correlates of creativity and elementary school students' perceptions of individual and sociocultural factors. *European Journal of Psychology of Education*. https://doi.org/10.1007/s10212-024-00876-9

Kelly, R. (2016). *Creative development: Transforming education through design thinking, innovation, and invention*. Brush Education.

Kijima, R., Yang-Yoshihara, M., & Maekawa, M. S. (2021). Using design thinking to cultivate the next generation of female STEAM thinkers. *International Journal of STEM Education, 8*(1), 1–15. https://doi.org/10.1186/s40594-021-00271-6

King, R. B. (2012). How you think about your intelligence influences how adjusted you are: Implicit theories and adjustment outcomes. *Personality and Individual Differences, 53*, 705–709. https://doi.org/10.1016/j.paid.2012.05.031

Kuo, H. C., Yang, Y. T. C., Chen, J. S., Hou, T. W., & Ho, M. T. (2021). The impact of design thinking PBL robot course on college students' learning motivation and creative thinking. *IEEE Transactions on Education, 65*(2), 124–131. https://doi.org/10.1109/TE.2021.3098295

Liedtka, J., King, A., & Bennett, K. (2013). *Solving problems with design thinking: Ten stories of what works*. Columbia University Press.

Lin, C. S., & Wu, R. Y. W. (2016). Effects of web-based creative thinking teaching on students' creativity and learning outcome. *Eurasia Journal of Mathematics, Science and Technology Education, 12*(6), 1675–1684. https://doi.org/10.12973/eurasia.2016.1558a

Liu, B., Shah, T. A., & Shoaib, M. (2024). Creative leadership, creative mindset and creativity: A self-regulatory focus perspective. *Current Psychology*. https://doi.org/10.1007/s12144-024-06066-6

Maxwell, J. A. (2010). Using numbers in qualitative research. *Qualitative Inquiry, 16*(6), 475–482. https://doi.org/10.1177/1077800410364740

Mardell, B., Rivard, M., & Krechevsky, M. (2012). Visible learning, visible learners: The power of the group in a kindergarten classroom. *YC Young Children, 67*(1), 12–16.

Neale, J., Miller, P., & West, R. (2014). Reporting quantitative information in qualitative research: Guidance for authors and reviewers. *Addiction, 109*(2), 175–176. https://doi.org/10.1111/add.12408

O'Connor, A. J., Nemeth, C. J., & Akutsu, S. (2013). Consequences of beliefs about the malleability of creativity. *Creativity Research Journal, 25*(2), 155–162. https://doi.org/10.1080/10400419.2013.783739

Organization for Economic Co-operation and Development. (2019). The *future of education and skills 2030 project*. Retrieved from https://www.oecd.org/education/2030-project/teaching-and-learning/learning/learning-compass-2030/OECD_Learning_Compass_2030_Concept_Note_Series.pdf.

Ozyaprak, M. (2016). The effectiveness of SCAMPER technique on creative thinking skills. *Journal for the Education of Gifted Young Scientists, 4*(1), 31–40.

Papalazarou, C. (2015). Making thinking visible in the English classroom: Nurturing a creative mindset. In A. Maley & N. Peachey (Eds.), *Creativity in the English language classroom* (pp. 37–43). British Council.

Paunesku, D. (2013). *Scaled-up social psychology: Intervening wisely and broadly in education*. Stanford University.

Plucker, J. A., Beghetto, R. A., & Dow, G. T. (2004). Why isn't creativity more important to educational psychologists? Potentials, pitfalls, and future directions in creativity research. *Educational Psychologist, 39*(2), 83–96. https://doi.org/10.1207/s15326985ep3902_1

Pressman, A. (2018). *Design thinking: A guide to creative problem solving for everyone*. Routledge. https://doi.org/10.4324/9781315561936

Project Zero. (2022). Visible thinking. Retrieved from http://www.pz.harvard.edu/projects/visible-thinking.

Rawlinson, J. G. (2017). *Creative thinking and brainstorming*. Routledge. https://doi.org/10.4324/9781315259000

Ritchhart, R., Church, M., & Morrison, K. (2011). *Making thinking visible: How to promote engagement, understanding, and independence for all learners*. Wiley.

Rosba, E., Zubaidah, S., & Mahanal, S. (2021). Digital mind map assisted group investigation learning for college students' creativity. *International Journal of Interactive Mobile Technologies*. https://doi.org/10.3991/ijim.v15i05.18703

Saggar, M., Quintin, E. M., Bott, N. T., Kienitz, E., Chien, Y. H., Hong, D. W., et al. (2017). Changes in brain activation associated with spontaneous improvization and figural creativity after design-thinking-based training: A longitudinal fMRI study. *Cerebral Cortex, 27*(7), 3542–3552. https://doi.org/10.1093/cercor/bhw171

Seelig, T. (2012). *inGenius: A crash course on creativity*. HarperOne.

Sternberg, R. J., & Lubart, T. I. (1991). An investment theory of creativity and its development. *Human Development, 34*(1), 1–31. https://doi.org/10.1159/000277029

Suchyadi, Y., Safitri, N., & Sunardi, O. (2020). The use of multimedia as an effort to improve elementary teacher education study program college students' comprehension ability and creative thinking skills in following science study courses. *Journal of Humanities and Social Studies, 4*(2), 201–205. https://doi.org/10.33751/jhss.v4i2.2549

Taylor, C. L., & Barbot, B. (2021). Gender differences in creativity: Examining the greater male variability hypothesis in different domains and tasks. *Personality and Individual Differences, 174*, 110661. https://doi.org/10.1016/j.paid.2021.110661

Valgeirsdottir, D., & Onarheim, B. (2017). Studying creativity training programs: A methodological analysis. *Creativity and Innovation Management, 26*(4), 430–439. https://doi.org/10.1111/caim.12245

Wilson, A., Howitt, S., & Higgins, D. (2016). Assessing the unassessable: Making learning visible in undergraduates' experiences of scientific research. *Assessment & Evaluation in Higher Education, 41*(6), 901–916. https://doi.org/10.1080/02602938.2015.1050582

Wolcott, M. D., McLaughlin, J. E., Hubbard, D. K., Rider, T. R., & Umstead, K. (2021). Twelve tips to stimulate creative problem-solving with design thinking. *Medical Teacher, 43*(5), 501–508. https://doi.org/10.1080/0142159X.2020.1807483

Wu, T.-T., & Wu, Y.-T. (2020). Applying project-based learning and SCAMPER teaching strategies in engineering education to explore the influence of creativity on cognition, personal motivation, and personality traits. *Thinking Skills and Creativity, 35*, 100631.

Yeager, D. S., & Dweck, C. S. (2012). Mindsets that promote resilience: When students believe that personal characteristics can be developed. *Educational Psychologist, 47*(4), 302–314. https://doi.org/10.1080/00461520.2012.722805

Yeh, Y. (2017). Research development of creativity. In J. Stein (Ed.), *Reference module in neuroscience and biobehavioral psychology* (pp. 1–11). Elsevier. https://doi.org/10.1016/B978-0-12-809324-5.06266-0

Yeh, Y. (2020). *Implementing mindful learning intervention through digital technology to enhance creativity: An exploration of neural plasticity.* Project report (MOST 107-2511-H-004 -002 -MY2), Ministry of Science and Technology, Taiwan.

Yeh, Y., Tsai, J. L., Hsu, W. C., & Lin, C. F. (2014). A model of how working memory capacity influences insight problem solving in situations with multiple visual representations: An eye tracking analysis. *Thinking Skills & Creativity, 13*, 153–167. https://doi.org/10.1016/j.tsc.2014.04.003

Yeh, Y., Chang, H. L., & Chen, S. Y. (2019). Mindful learning: A mediator of mastery experience during digital creativity game-based learning among elementary school students. *Computers & Education, 132*, 63–75. https://doi.org/10.1016/j.compedu.2019.01.001

Yeh, Y., Chang, C. Y., Ting, Y. S., & Chen, S. Y. (2020a). Effects of mindful learning using a smartphone lens in everyday life and beliefs toward mobile-based learning on creativity enhancement. *Educational Technology & Society, 23*(4), 45–58.

Yeh, Y., Sai, N. P., & Chuang, C. H. (2020b). Differentiating between the "Need" for and the "experience" of self-determination regarding their influence on pupils' learning of creativity through story-based digital games. *International Journal of Human-Computer Interaction, 14*, 1368–1378. https://doi.org/10.1080/10447318.2020.1750793

Yeh, Y., Chang, J. I., & Ting, Y. S. (2022). Engaging elementary school children in mindful learning through story-based creativity games facilitates their growth mindset. *International Journal of Human-Computer Interaction*. https://doi.org/10.1080/10447318.2022.2041901

Yeh, Y., Ting, Y. S., & Chiang, J. L. (2023). Influences of growth mindset, fixed mindset, grit, and self-determination on self-efficacy in game-based creativity learning. *Educational Technology & Society, 26*(1), 62–78.

Zhao, L., Liu, X., Wang, C., & Su, Y. (2022). Effect of different mind mapping approaches on primary school students' computational thinking skills during visual programming learning. *Computers & Education, 181*, 104445. https://doi.org/10.1016/j.compedu.2022.104445

Zhao, S., Yu, C., Jin, L., & Lin, D. (2023). Helping students to face academic failures: Evaluation of a growth mindset intervention among primary school students in China. *Applied Psychology: Health and Well-Being*. https://doi.org/10.1111/aphw.12496

Karwowski, M. (2014). Creative mindsets: Measurement, correlates, consequences. *Psychology of Aesthetics,Creativity, and the Arts, 8*(1), 62–70.

Guo, J., Islam, A. Y. M. A., Teo, T., & Spector, J. M. (2019). Computer-enabled visual creativity: An empiricallybasedmodel with implications for learning and instruction. *Instructional Science: An International Journal of theLearning Sciences, 47*(5), 609–625.

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