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Effects of design thinking on artificial intelligence learning and creativity

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ABSTRACT

This study explored the effects of design thinking on the conceptual cognition of artificial intelligence (AI) learning, attitudes toward AI, idea creativity, and the product creativity of AI applications. The concept map indicated that design thinking had a significant effect on the conceptual cognition of AI learning, particularly the relational conjunctions and classes of AI concepts. However, effects of cross-linking and examples were nonsignificant. In addition, it had a significant and positive effect on learning attitudes toward AI, in particular AI input and AI processing. Moreover, design thinking significantly and positively affected the idea creativity of AI applications, particularly the effects of novelty and value. It also had a significant and positive effect on the product creativity of AI applications, particularly functionality and elaboration. However, material novelty, style, idea structure, and product creativity had no significant difference.

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Design thinking; artificial intelligence learning; creativity

1. Research background and motivation

In the face of rapid technological development and social change, design thinking has become an essential instructional strategy for cultivating the skills required in the 21st century (Lin et al. 2020; European Union 2020). It is used to guide the instruction of traditional subjects for cultivating student skills (Lin et al. 2020; European Union 2020). For example, the European Union's Horizon 2020 plans emphasize design thinking. It is an innovative methodology that relies on complex skills, processes, and mindsets. It helps learners to produce novel works and develop their creative thinking skills (Lin et al. 2020). Companies such as Toyota, Starbucks, Microsoft, and Apple have integrated professionalism and creativity through design thinking to promote innovation performance (Albay & Eisma, 2021; de Figueiredo 2021).

Artificial intelligence (AI) refers to the phenomenon whereby machines think and act in ways that imitate human intelligence. AI has been recently attracted increasing research efforts towards solving the complex issues in a number of fields, including engineering, medicine, economy, and psychology (Jamshidi et al. 2020). AI has rapidly and considerably affected industries and human lifestyles as well (Schwendicke, Samek, and Krois 2020;

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Haefner et al. 2021; Wamba et al. 2021; Lopez, Miller, and Tucker 2019). Various studies have noted that AI can improve human skills with respect to quality of design, manufacturing, decision management, and health care, and continues to drastically change people's lives (Zhang et al. 2021; Klaus and Zaichkowsky 2021). Therefore, AI education and learning have become the focus of developed countries (Hsu et al. 2021).

Due to the rapid development of AI, conventional learning approaches are no longer sufficient in some respects. Design thinking promotes active learning, constructivist learning, and creativity (Albay & Eisma, 2021). Research has revealed that the application of design thinking affects learning in mathematics (Albay & Eisma, 2021), management (de Figueiredo 2021), and engineering (Mahajan et al. 2021) as well as the development of innovation ability (Pande and Bharathi 2020), problem-solving ability (Pande and Bharathi 2020), and creativity (Latorre-Cosculluela et al. 2021). Therefore, determining the optimal use of design thinking, including user-centered iterative perspectives, problem-solving abilities, multidisciplinary learning, and complex backgrounds (de Figueiredo 2021), to enable students to understand AI and achieve creative learning outcomes, is a crucial yet challenging task (Esling and Devis 2021). Consequently, this study explored the effects of design thinking on the conceptual cognition of AI learning, attitudes toward AI, and the idea creativity and product creativity of AI applications.

2. Literature review

2.1. Instructional strategies for design thinking

Design thinking is an innovative method that uses an iterative process to deliver user- and customer-oriented results to solve complex problems (Uebernickel et al. 2020; Dell'Era et al. 2020). Design thinking is widely applied in product design, engineering, management, and business and has a considerable effect on firm innovation (Micheli et al. 2018; Dell'Era et al. 2020). According to an analysis of 47 companies in Italy, there are five practical aspects of design thinking (Dell'Era et al. 2020), which can also be used as the basis for design thinking instructional applications. These are human-centered design, comprising user involvement, empathy with humans, and a focus on context; problem framing, consisting of framing and reframing problems, engaging in abductive reasoning, and embracing ambiguity; diversity, including integrative thinking, holistic thinking, and interdisciplinary collaboration; experimentation, encompassing learning by doing, failing often and soon, and diverging or converging; and visualization, which entails making ideas and insights visual and tangible as well as representing abstract concepts.

Common design thinking models include the "inspiration, ideation, and implementation", "empathy, define, ideate, prototype, and test", "understand, explore, prototype, and evaluate", and "empathy, ideation, and experimentation" models (Micheli et al. 2018; European Union 2020). Content analyses have revealed that the most commonly used tools are ethnographic methods, personas, journey maps, brainstorming, mind maps, visualization, prototyping, and experiments (Micheli et al. 2018). Design thinking has crucial applications in the fields of law, business, science, medicine, engineering, and management (Pande and Bharathi 2020). For example, a college in India implemented a compulsory design thinking course and used constructivist learning as the theoretical basis for developing design thinking textbooks (Pande and Bharathi 2020).

Design thinking skills are particularly important for cultivating problem solving and innovation abilities in the 21st century (Pande and Bharathi 2020). It can be useful for solving highly specialized and complex problems (Mosely, Wright, and Wrigley 2018; Pande and Bharathi 2020). In the field of management research, it can promote the integration of theory and practice (de Figueiredo 2021). Studies have found that in mathematics education, design thinking learning exhibits obvious learning effects on scientific inquiry, computing skills, and mathematics majors (Albay & Eisma, 2021). In engineering education, it helps students to become more proficient in engineering design and in the generation of outstanding design outputs (Mahajan et al. 2021). In addition, it positively impacts student creativity and self-confidence (Latorre-Cosculluela et al. 2021).

In instructional implementation, design thinking can be used to promote multidisciplinary learning (de Figueiredo 2021), an in-depth background with complex situations, empathy, cooperation, creative problem solving, innovation, motivation, and attitude (de Figueiredo 2021; Albay & Eisma, 2021). Teaching design thinking through project-based learning can help students understand their needs and solve problems using the design thinking process (Mahajan et al. 2021). Such teaching further enhances the value diversity and originality of student output, which allows students to consolidate their professional knowledge and develop creativity and learning motivation (Lin et al. 2020).

2.2 AI and education

AI refers to intelligent machinery that can make decisions based on rational human-like thinking and actions through computer programming (Schwendicke, Samek, and Krois 2020). In recent years, information technology has advanced at the speed of Moore's law (Haefner et al. 2021), and developers have attempted to improve technology-oriented production by augmenting human and machine intelligence (Yang et al. 2021), which is beneficial for enhancing production lines, creativity, and the design process (Utz and DiPaola 2020). According to Lopez, Miller, and Tucker (2019), a well-trained AI machine can perform as well as human designers or may even outperform designers in specific design tasks.

AI also plays an unprecedentedly critical role in the engineering design process (i.e. customer preference identification, concept generation, concept evaluation, prototyping, and manufacturing) (Zhang et al. 2021; Camburn et al. 2020) and the supply chain of products and services (i.e. decision-making, design, manufacturing, marketing, and logistics) (Klaus and Zaichkowsky 2021; Schwendicke, Samek, and Krois 2020; Wamba et al. 2021). Rapid developments are ongoing with respect to AI inputs (e.g. sensing elements and data generation), AI processes (i.e. cloud computing hardware and software), and AI outputs (i.e. decision support systems and robotic integration), which are components of the AI input–process–output model (or input-selection-techniques-optimization-output /design-optimization-production) (Jamshidi et al. 2020, 2021). AI is thus infiltrating society and daily life in the form of machines with human-like thinking abilities (Wamba et al. 2021; Figure 1). The following hypotheses are proposed based on the aforementioned discussion:

H1: Design thinking strategies significantly affect the conceptual cognition of AI learning.

AI input–process–output model

	Natural Intelligence	Artificial Intelligence: Machine learning	Artificial Intelligence: Deep learning	Major technology
Input	Perception	Data & outcomes Engineered features	Data & outcomes	Big data Sensing element Artificial intelligence of things
Process	Interpretation	Feature mapping	Feature learning & mapping	Algorithm Cloud computing Natural language
		Interpretation	Interpretation	
Output	Response	Actions & applications		Decision support Robot

Figure 1. AI input–process–output model. Source: Modified from Schwendicke, Samek, and Krois (2020).

H2: Design thinking strategies significantly affect learning attitudes toward AI.

AI not only constitutes educational content but is also a tool for promoting education. Precision education and intelligent learning are the two primary areas of AI applications (Yang et al. 2021). Diagnosis, prediction, treatment, and prevention are the four major steps of precision medicine and the four main aspects of precision education (Yang et al. 2021). The main direction is the inspection of the effects of the development and application of new pedagogical models (i.e. teaching and learning methods) and learning tools (i.e. digital platforms) (Yang et al. 2021). AI applications in intelligent learning include diagnosing learning difficulties, confirming learning outcomes, evaluating effective learning strategies, categorizing learning patterns, defining learning motivation and engagement, and establishing differentiated and individualized learning (Tempelaar, Rienties, and Nguyen 2021; Yang et al. 2021).

However, research on AI in education has focused only on machine learning, natural language processing, deep learning, and other advanced techniques, which can still be improved using educational theories in physical classroom settings (Chen et al. 2020). In terms of creative learning, AI systems that imitate human cognition and creativity can simulate divergent thinking, concept blending, and creative honing theory (DiPaola, McCaig, and Gabora 2018; Utz and DiPaola 2020).

2.3 Creative expression and AI

Creativity refers to the ability to produce novel and useful ideas and products (Amabile 1996; Mikalef and Gupta 2021; Esling and Devis 2021; Nazzal and Kaufman 2020). The process and result must be considered when evaluating creativity (Esling and Devis 2021).

The purposes of creative product evaluation may vary. For example, it can be performed to assess the creative expression of students. Such evaluations focus on products' novelty and usefulness (Chang et al. 2016). Product evaluations that examine society's aesthetic and elaboration requirements can also be performed to improve products for commercialization (Lan and Kaufman 2013). The scoring items in creative product evaluation are novelty, resolution, and elaboration (Besemer 1998; Mazerant et al. 2021;

Weisberg et al. 2021). From the perspective of product design, some scholars have classified the dimensions of product creativity into material, function, structure, and style (Chang and Yu 2015), which can guide designers or students in creative design.

In addition to the aforementioned assessment items, the Creative Product Semantic Scale (Besemer 1998; Mazerant et al. 2021), Student Product Assessment Form (Reis and Renzulli 1991), and Creative Idea Scale (Chang and Yu 2015) can be used to evaluate products; however, these scales are based on the novelty, resolution, and elaboration framework. To assess product creativity, the Consensual Assessment Technique (Amabile 1996; Nazzal and Kaufman 2020; Stemler and Kaufman 2020), Likert scale (Mazerant et al. 2021; Weisberg et al. 2021), and Overall Creativity Scoring items (Nazzal and Kaufman 2020) are sufficiently mature and have high reliability and validity (Chang et al. 2016). Stemler and Kaufman (2020) examined the differences in the scoring results of raters with different professional backgrounds.

The application of AI may have positive effects on creative expression in various professional fields, including engineering, design, management, and art (Mikalef and Gupta 2021; Mazzone and Elgammal 2019). Analyses of 72 research papers on architectural design from the last 25 years revealed that genetic algorithms and evolutionary computing have been widely applied in architectural design. Evolutionary computing is often used to produce innovative, creative, efficient, and aesthetically pleasing architectural objects with excellent performance. Genetic algorithms are used to handle large problems and to achieve an optimal balance between multiple design criteria and design solutions (Pena et al. 2021). Studies have indicated that designers can overcome design limitations and produce design works based on new concepts using AI and three-dimensional software (Buonamici et al. 2020). AI can be used not only to generate design solutions based on clear design requirements but also to combine experience and creativity for the exploration of design requirements and possible design solutions (Pena et al. 2021).

In addition to the productivity and quality of engineering and design, organizational creativity performance can be improved using AI. The effects of AI on organizational creativity performance has attracted considerable research attention (Mikalef and Gupta 2021; Townsend and Hunt 2019). Mikalef and Gupta (2021) revealed that an organization's AI capabilities can directly affect its creativity and performance and enhance its employees' individual creativity. Deep learning has become a useful AI tool for enhancing creativity (Esling and Devis 2021). Esling and Devis (2021) proposed the viewpoint of artificial creativity for integrating the intelligence and computing power of AI. On the basis of the aforementioned discussion, the following hypotheses are proposed:

H3: Design thinking strategies significantly affect the idea creativity of AI applications.

H4: Design thinking strategies significantly affect the product creativity of AI applications.

3. Research design and implementation

3.1. Research participants

This study explored the effects of design thinking on the conceptual cognition of AI learning, attitudes toward AI, and the idea creativity and product creativity of AI applications. The participants in this study were selected from a grade 11 science and technology elective class (average age = 17 years) in a public high school in Taipei City, Taiwan. There were 32 participants, divided into a control group and an experimental group comprising 16 students each. The differences in the mean scores of the two groups in the previous semester were nonsignificant ($t = 4.9$, $p = .63$).

3.2. Independent variable

A nonequivalent post-test-only quasi-experiment design was adopted in this research. The independent variable of this study was the instructional strategies used. The experimental group was taught using the instructional strategy of design thinking, whereas the control group was taught using conventional narrative teaching and AI demonstration exercises. In addition to AI narration and demonstration exercises, the experimental group participated in design thinking activities. The design thinking process involved developing empathy, defining problems and goals, ideation, prototyping, testing, and correction. The devices used in the aforementioned process were a Pixetto image recognition lens module, which was used for the creation and recognition of neural network image models, and an Arduino controller, which was used to receive the Pixetto signal and drive the motor. The two groups' instructional processes are presented in Table 1.

3.3 Dependent variable

The dependent variables in this study were AI concepts, attitudes toward AI, idea creativity, and product creativity. AI concepts were scored according to the concept map that the students drew. Relational conjunctions were used to present the relationships between concept words, and each valid conjunction was assigned 1 point. Class represents the hierarchical relationship between knowledge concepts. Among the overall longest class, and each effective class was assigned 5 points. Cross-linking was performed to determine the relationship between different classes of concept words, and each cross-link was assigned 10 points. Examples were used to illustrate the particularity of domain knowledge, and one point was assigned to each example. Cronbach's alpha was 0.67 (Novak and Gowin 1984; Plummer 2008) and the correlation coefficient between the two raters' scores was 0.75, representing high consistency (Mugenda and Mugenda 2003).

The participants' attitudes toward AI were determined by segmenting the words that the students wrote, deleting irrelevant vocabulary, merging synonyms, and drawing them on a word cloud platform. The WordArt tool available at https://wordart.com/create?fbclid=IwAR2PosYhHh8cg6er8y5ZDB9edTr4NT8hYq9MyIgRemg6UkGgPZ4ISgYoI was used for drawing. Word clouds are a tool for data visualization and affective computing (Chintalapudi et al.

Table 1. Main instructional procedures.

Week	Stage	Experimental group	Control group
1	Introduction to AI	With multimedia explanation (1) The concept and real-life application of AI (2) Machine learning (supervised learning, unsupervised earning, and reinforcement learning) (3) Deep learning	With multimedia explanation (1) The concept and real-life application of AI (2) Machine learning (supervised learning, unsupervised learning, and reinforcement learning) (3) Deep learning
2	Design thinking exercise	(1) Image recognition and real-life AI application (2) Learning task 1 of design thinking (application of the Arduino controller)	(1) Image recognition and real-life AI application (2) Application practice for the Arduino controller
3	Design thinking exercise	1. Learning task 2 of design thinking (combined application of the Pixetto image recognition module and Arduino controller)	(1) Actual application of the Arduino controller (2) Combined application practice of the Pixetto image recognition module and Arduino controller
4	Empathy development, problem defining, and goal ideation	(1) Examination of the problems that you and the people around you will encounter in life (2) Selection of the problem and setting of the goal (3) Brainstorming to develop multiple plans and deciding which plan to use	(1) Experience sharing (2) Concept map learning (3) Drawing of an AI concept map
5	Prototyping test and correction	(1) Design and production of the AI work structure and organization (2) Programming of AI works (3) Testing and correction of AI works	(1) Elective course on scientific inquiry
6	Prototyping test and correction	1. Design and production of the AI work structure and organization 2. Programming of AI works 3. Testing and correction of	(1) Elective course on scientific inquiry
7	Result presentation	1. Presentation of AI works 2. Concept map learning 3. Drawing of an AI concept map	1. Elective course on scientific inquiry

2021; Bilro, Loureiro, and de Aires Angelino 2021). In the present study, three doctoral students with expertise in science and technology education established a consensus on the adopted procedures; thus, expert validity was achieved (Chintalapudi et al. 2021).

Idea creativity denotes the process by which the experimental group adopted AI as the main tool for performing design thinking activities and proposing an innovative solution plan. The scoring items for idea creativity were novelty (material, style, and structure), newness (originality and unusualness), feasibility (specificity and completeness), and value (aesthetic, functionality, and multipurpose) (Besemer 1998; Chang and Yu 2015; Mazerant et al. 2021; Weisberg et al. 2021). The aforementioned items were scored by two senior instructors. The correlation coefficients between the novelty, newness, feasibility, and value scores provided by the two instructors were 0.81, 0.72, 0.85, and 0.79, respectively, indicating satisfactory reliability (Mugenda and Mugenda 2003).

Product creativity indicates the novelty (product, material, and design), function (functionality, effectiveness, and durability), and elaboration (elaborate and aesthetic) of AI works (Chang and Yu 2015) in accordance with the rubrics. The aforementioned parameters were scored by two senior instructors. The correlation coefficients by the two instructors were 0.75, 0.84, and 0.77, respectively, indicating satisfactory reliability (Mugenda and Mugenda 2003).

3.4 Implementation procedures

Because the experiment conducted in this study was in line with the school's formal elective courses and most of the students had never learned AI, a nonequivalent control group post-test-only design (Krishnan 2019) was adopted. The present study first collected students' scores for science and technology courses in the previous semester prior to conducting the teaching experiments. After the experiments, the AI concepts, attitudes toward AI, idea creativity, and product creativity were tested and scored.

3.5 Data analyses

Pre-test data were unavailable because this study adopted a nonequivalent control group post-test-only design (Krishnan 2019). Therefore, *t*-tests and chi-square tests were conducted according to data type to assess the difference between the post-test performances of the experimental and control groups.

4. Research results

4.1. Cognition of AI concepts

According to the *t*-test results (Table 2), the experimental group outperformed the control group with respect to their cognition of AI learning concepts ($t = 2.39$, $p < 0.05$, Cohen's $d = 1.01$), relational conjunctions ($t = 2.17$, $p < 0.05$, Cohen's $d = 1.05$), and class performance ($t = 2.72$, $p < 0.05$, Cohen's $d = 1.22$) (Figure 2). The concept map drawn by the students is presented in Figure 3.

Table 2. Results of the *t*-test for the cognition of AI concepts.

Item	Group	Mean	Standard deviation	t	Cohen's d
Relational conjunction	Experimental group	10.56	4.67	2.17*	1.05
	Control group	6.07	3.82		
Class	Experimental group	20.56	4.63	2.72*	1.22
	Control group	13.38	6.87		
Cross-linking	Experimental group	12.22	13.01	1.13	0.48
	Control group	6.15	11.92		
Example	Experimental group	0.44	1.33	0.97	0.38
	Control group	0.07	0.27		
Total	Experimental group	43.78	19.46	2.39*	1.01
	Control group	25.69	15.93		

*P < 0.05

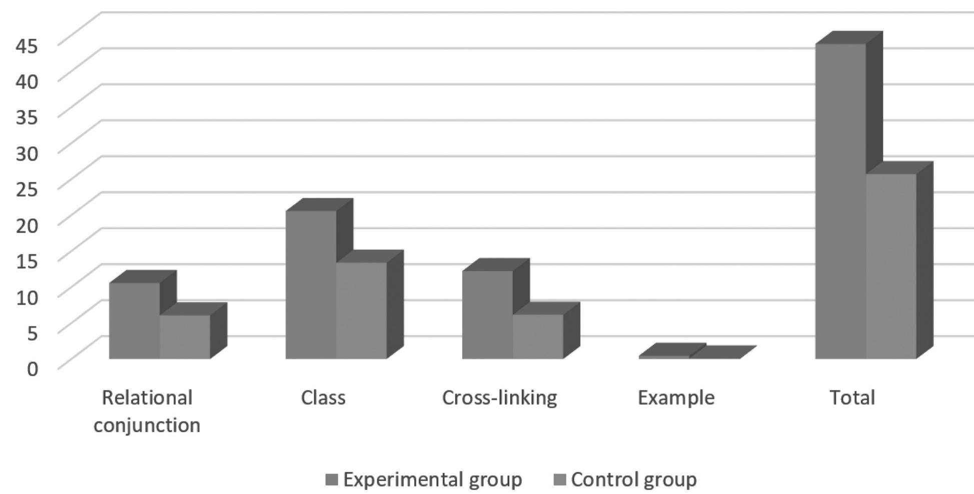

Figure 2. Mean scores associated with relational conjunction, class, cross-linking, example, and total score, compared between groups.

4.2 Attitude toward AI

The results of the chi-square test revealed that the experimental group exhibited higher vocabulary occurrences indicating positive attitude toward AI than did the control group (65 vs. 37) The differences in the two groups' content distributions were also statistically significant ($\chi^2 = 8.06$, $p = 0.45$). As Table 3 illustrates, the vocabulary occurrence numbers for AI input and AI processing were significantly higher for the experimental group than for the control group (8 vs. 3 and 22 vs. 4, respectively). Analyses of the word cloud indicated that the control group mainly focused on application content – for example, "AI, movies, life, and friends" – whereas the experimental group focused more on the technical terms associated with AI processing, such as "mechatronics, integration, and works" (Figures 4 and 5).

4.3 Idea creativity and product creativity of AI applications

Following the design thinking teaching, the students' design plans were graded according to a 7-point Likert scale for a total mean value of 4.0 in the *t*-test. The results presented in Table 4 indicate that the total score (18 vs. 16, $t = 18.52$, $p < 0.01$, Cohen's $d = 2.95$),

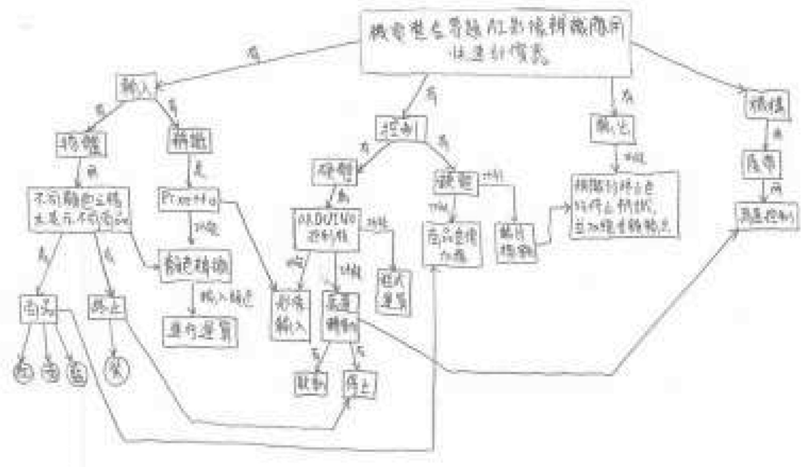

Figure 3. AI concept map drawn by the students.

Table 3. Number of vocabulary occurrences of positive attitudes toward AI.

	Input	Process	Output	Feedback	Total
1. Experimental group	8(7.8%)	22(21.6%)	17(16.7%)	18(17.6%)	65(63.7%)
2. Control group	3(2.9%)	4(3.9%)	14(13.7%)	16(15.7%)	37(36.3%)
Total	11(10.8%)	26(25.5%)	31(30.4%)	34(33.3%)	102(100%)

Figure 4. AI word cloud diagram of the control group.

newness score (5.3 vs. 4.0, $t = 2.91$, $p < 0.05$, Cohen's $d = 1.00$), and value score (4.8 vs. 4.0, $t = 3.47$, $p < 0.05$, Cohen's $d = 0.96$) were higher than the mean and attained a significant level with a large effect size (Murphy & Myors, 2004). However, although the mean feasibility score was higher than the total mean (5 vs. 4.0), the feasibility score had a nonsignificant level, likely owing to its large standard deviation (1.41). The students' design drawings are presented in Figure 6.

The product creativity of AI works was evaluated using a 7-point Likert scale with a total mean of 4.00 in the *t*-test. The results presented in Table 5 reveal that the total score (14 vs. 12, $t = 33.2$, $p < 0.01$, Cohen's $d = 2.85$), functionality score (4.8 vs. 4.0, $t = 2.65$, $p < 0.05$, Cohen's $d = 0.73$), and elaboration score (4.8 > 4.0, $t = 3.47$, $p < 0.05$, Cohen's $d = 0.96$) were higher than the total mean and achieved significant levels with a large effect size (Murphy

Figure 5. AI word cloud diagram of the experimental group.

Table 4. Results of the *t*-test for idea creativity.

Item	n	Mean	Standard deviation	*t*	Cohen's d
Novelty	16	4.00	.70	1.58	0.38
Newness	16	5.30	1.30	2.91*	1.00
Feasibility	16	5.00	1.41	2.37	0.70
Value	16	4.80	0.83	3.47*	0.96
Total	16	19.00	1.87	18.52**	2.95

*$P < 0.05$; **$P < 0.01$

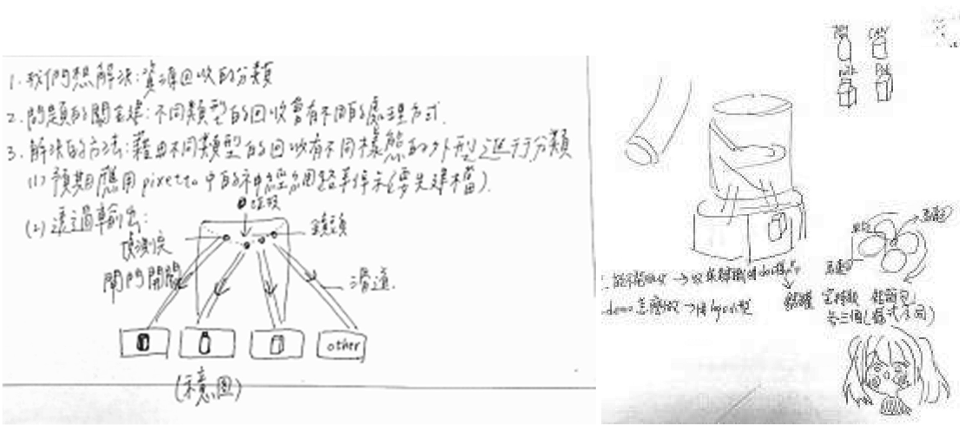

Figure 6. Design drawings of the recycling device.

& Myors, 2004). However, although the mean novelty score was higher than the total mean (4.4 vs. 4.0), the novelty score had a nonsignificant level, possibly owing to its large standard deviation (0.89). The work that the students produced is illustrated in Figure 7.

Table 5. Results of the *t*-test for product creativity.

Item	n	Mean	Standard deviation	*t*	Cohen's d
Novelty	16	4.40	0.89	2.25	0.44
Functionality	16	4.80	1.09	2.65*	0.73
Elaboration	16	4.80	0.83	3.47*	0.96
Total	16	14.00	0.70	33.2**	2.85

*P < 0.05; **P < 0.01

Figure 7. AI work created by the students (i.e. a detection system that can identify whether students are wearing school uniforms).

5. Discussion

5.1 Effect of design thinking strategies on the conceptual cognition of AI learning

This study's findings indicate that design thinking had a significant effect on the conceptual cognition of AI learning, particularly the relational conjunctions and classes of AI concepts. The concept map emphasizes the establishment of a situational model knowledge system (Wandersee 1990) and can enhanced participants' learning of complex problem-solving techniques (Hwang, Zou, and Lin 2020; Prasetya, Hirashima, and Hayashi 2020). Studies have found that design thinking affects how students learn complex and integrated concepts (Pande and Bharathi 2020; de Figueiredo 2021); the present study's results are in line with those findings. Design thinking is based on abductive reasoning by virtue of its focus on contextual and holistic thinking (Dell'Era et al. 2020), whereas engineering science thinking is based on deductive reasoning (Auernhammer, Sonalkar, and Saggar 2020).

The concept-learning effects of cross-linking and examples were nonsignificant. This result may potentially be attributed to the students' inadequate exposure to and experience with AI (Hu, Lu, and Gong 2021), for which fewer examples were shown; therefore, the students exhibited low ability to express concepts across classes. Educators should investigate how students' AI experience may be enriched and how high-level cross-class expression abilities may be attained.

5.2 Effect of design thinking strategies on the learning attitude toward AI

In this study, design thinking had a significant and positive effect on learning attitudes toward AI, consistent with the results of related studies (Lin et al. 2020; Albay & Eisma, 2021). In terms of the input–process–output model of AI, the experimental group's positive attitude toward AI input and processing was significantly higher than that of the control group. Studies have indicated that design thinking has a positive effect on the integration of professional learning and motivational attitudes (Mosely, Wright, and Wrigley 2018; Pande and Bharathi 2020; de Figueiredo 2021; Lin et al. 2020). Moreover, empirical research has revealed that it can improve girls' positivity toward technological learning and creativity (Kijima, Yang-Yoshihara, and Maekawa 2021). Other research has claimed that design thinking can generate positive attitudes because students must first deeply empathize with user needs (close to the level of immersion) and then contribute design output to users and receive benefits from users (Martins et al. 2019).

The experimental group used AI input resources and processing technology to create and develop work in the design thinking program. This project-based learning of real-life applications enhanced the students' learning attitudes (Mahajan et al. 2021). Enhancement of students' learning attitudes, particularly with respect to rigid AI technology learning, is a valuable outcome.

5.3 Effect of design thinking on the idea and product creativity of AI applications

In this study, design thinking had a significant and positive effect on the idea creativity of AI applications, particularly newness (originality and unusualness) and value (aesthetic, functionality, and multipurpose). Rao, Puranam, and Singh (2021) noted that design thinking has a positive effect on the fluency and elaboration of students' creativity. Other studies have revealed that design thinking positively affects students' creative thinking and performance (Lin et al. 2020; de Figueiredo 2021; Albay & Eisma, 2021); the results of the current study are consistent with this notion.

The results for the effects of the novelty and usefulness of materials, styles, and structures on learning were nonsignificant. This may be attributable to the students' lack of AI learning experience, contact experience, and practical experience. Therefore, when conceiving a plan, the students did not consider specific items, such as materials, styles, or structures; thus, the aforementioned parameters exhibited no obvious effects on the learning. Moreover, in line with Rao, Puranam, and Singh (2021), the effects of design thinking on the originality of students' creativity were nonsignificant, indicating that more effective guidance methods were required in the ideation stage.

Deign thinking had a significant and positive effect on the product creativity of AI applications, particularly functionality and elaboration or aesthetics, in line with previous studies (Mikalef and Gupta 2021; Mazzone and Elgammal 2019; Rao, Puranam, and Singh 2021), which have also noted that AI is not only applicable to learning content but is also a tool for creative design that can assist creative expression (Buonamici et al. 2020). The visual recognition module used in this study can fully support students' ideation and thereby contribute to the enhancement of product creativity. The novelty (products, materials, and design) of the AI works fell short of expectations, possibly owing to the students' lack of experience in the materials of AI creation and the design production procedure; thus, more effective approaches were required to guide ideation. This problem was identical to that observed in relation to idea creativity.

6. Conclusion and recommendations

6.1 Research Conclusions and Recommendations for Practical Application

This study explored the effects of design thinking on the conceptual cognition of AI learning, attitudes toward AI, and idea and product creativity of AI applications. The study's main conclusions are as follows:

(1) According to the results of the concept map evaluation, design thinking had a significant effect on the conceptual cognition of AI learning, particularly the relational conjunctions and classes of AI concepts. However, the concept-learning effects of cross-linking and examples were nonsignificant. In the future, elementary-, secondary-, or even tertiary-level courses with additional AI experience and learning opportunities should be provided to students through teaching based on thematic or immersive design thinking.

(2) Design thinking significantly and positively affected learning attitudes toward AI, particularly enhancing positive attitudes toward AI input and AI processing. This result may be explained by the fact that in-depth user-centered thinking and design outcomes are applicable in real life and thus promote positive attitudes toward rigid AI technology learning. Accordingly, thematic and project-based, and daily life contextual design thinking would be an appropriate instructional design for AI technology learning.

(3) Design thinking had a significant and positive effect on the idea creativity of works created using AI, particularly the novelty and value of these works. In addition, it had a significant and positive effect on the product creativity of works created using AI, particularly the functionality and elaboration of these works. However, the novelty of ideas and product creativity in terms of material, style, and structure was nonsignificant. When using design thinking for AI teaching in the future, more diversified ideation tools, such as the SCAMPER (substitute, combine, adapt, modify, put to another use, eliminate, reverse) technique, brainstorming, the Six Thinking Hats model, and attribute listing (Mikalef and Gupta 2021; Esling and Devis 2021), can be provided in the ideation stage and combined with the learning of AI professional technology for improving the creative expression of students.

6.2 Research limitations and recommendations for future research

Design thinking involves aspects such as user-centered iterative perspectives, problem solving, multidisciplinary learning, and complex backgrounds (de Figueiredo 2021), which are particularly meaningful and valuable in the teaching and application of new technologies, such as AI. It has different levels of effects on the conceptual cognition of, attitude toward, and creative expression of AI learning. Its effects on conceptual cognitive performance are related to students' professional level, which can be used as a mediator or moderator in the research design. The effects of design thinking on creative expression are related to the guidance of creative thinking technology, which can be explored as a moderator. Furthermore, when limited to the implementation of elective courses, the AI teaching time and method used for the control group in this study may be more rigorously controlled to examine the effects of design thinking on AI learning and creative expression with greater accuracy.

Note

The English in this document has been checked by at least two professional editors, both native speakers of English. For a certificate, please see:http://www.textcheck.com/certificate/KZ6xDx

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