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Research Article

Exploring the Effectiveness of Reverse Engineering Pedagogy in a Culture-Oriented STEAM Course: From Heritage to Creativity

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Abstract: This research innovatively combines culture-based Culture-STEAM (C-STEAM) with Reverse Engineering pedagogy, aiming to explore the effectiveness of C-STEAM Reverse Engineering Teaching Mode on students' Creative Thinking, Cultural Competence and Engineering Thinking. The study was conducted in an STEAM course of 90 undergraduate students major in Educational Technology. Based on the observation of the pilot study (Study 1), we refined the research design and accessed its efficacy through quasi-experimental design in the formal study (Study 2). The results indicate that the experimental group outperformed the control group in aspects of Creative Thinking. Such as the Rationality, Concreteness, Generate Precise Ideas and Improve Idea. Both the experimental and control groups exhibited significant improvement in terms of the Value, Accuracy, and Logicality of Creative Thinking, overall Cultural Competence, Cultural Understanding, Cultural Identity, and Engineering Thinking. However, the two groups of students did not show significant progress in Generate Diverse Ideas, Flexibility and Evaluate Idea within Creative Thinking, as well as Cultural Practice within Cultural Competence. The study underscores the value of the C-STEAM Reverse Engineering Teaching Mode, particularly in enhancing students' Creative Thinking, Cultural Competence, and Engineering Thinking, which provides a reference example for teachers to cultivate students' ability. This study makes up for the gaps in C-STEAM related teaching mode innovation and explores possible directions for the future development of STEAM education. Nevertheless, it necessitates further refinement exploration of its internal mechanism.

Keywords: creative thinking, C-STEAM, reverse engineering pedagogy, teaching mode

1. Introduction

STEAM education is a powerful means of cultivating innovative talents and plays a significant role in driving national development, education reform, and innovation. It involves the seamless integration of science, technology, engineering, arts, and mathematics, constituting a practical framework for interdisciplinary education (Belbase et al., 2022). This approach leverages interdisciplinary knowledge and thinking to address real-world challenges, with the overarching goal of fostering students' innovative capabilities and comprehensive literacy. The cultivation of creative thinking is a cornerstone of this approach. C-STEAM (Culture-STEAM) education is an interdisciplinary approach that integrates cultural heritage and innovation, blending humanities with sciences. Its aim is to nurture innovative

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individuals who possess both a deep understanding of culture and heritage and strong creative thinking skills. By combining cultural understanding with creative thinking, C-STEAM seeks to cultivate scientific and technological talents who can gain insights into the cultural competence (Huo et al., 2020).

The Reverse Engineering Teaching mode, which involves disassembling and micro-innovating existing objects rather than designing them from the ground up, has been used to cultivate innovative skills in education. In C-STEAM education, students are guided to understand, explore, and create based on contextual perception. This approach applies the Reverse Engineering Teaching mode by having students disassemble and micro-innovate existing cultural artifacts instead of building cultural cognition and artifacts from scratch. This method may be more effective in cultivating students' creative thinking.

In response to recent global educational shifts, there is a clear emphasis on nurturing well-rounded individuals with a scientific mindset, innovative capabilities, and strong humanistic values. STEAM education is at the forefront of this movement, aiming to cultivate versatile individuals with a keen sense of innovation and the ability to innovate (Ramos-Gavilan et al., 2024). Exploring how to efficiently make STEAM education help cultivate innovative and complex talents has become a hot research topic nowadays.

Consequently, this study introduces the concept of the C-STEAM Reverse Engineering Teaching Mode, designed to nurture students' cultural competence and creative thinking. Specifically, it delves into the development and application of the C-STEAM Reverse Engineering Teaching Mode, with the aim of enhancing students' creative thinking, cultural competence, and engineering acumen within the context of C-STEAM education. Furthermore, it seeks to uncover the interplay between creative thinking and cultural competence. In conclusion, this study centers on developing a C-STEAM Reverse Engineering Teaching Model to enhance students' creative thinking, cultural competence, and engineering acumen. The model's effectiveness is examined through quasi-experiments, aiming to answer the research question: What impact does the practical application of the C-STEAM Reverse Engineering Teaching Mode have?

2. Literature review and hypothesis development

2.1 *C-STEAM*

In the context of composite talent training, the integration of STEAM education and culture has gradually attracted attention (Qian et al., 2023; Zhong et al., 2021). Currently, a few endeavors have been undertaken to integrate culture and STEAM in practical teaching, He et al. (2022) integrating sand tray into the STEAM teaching of local society and culture. Integrating the Chinese traditional culture into the virtual teaching resources (Yu et al., 2022). But these typically involve leveraging exemplary traditional Chinese culture and intangible cultural heritage as conduits within STEAM education courses (Lee & Hee, 2018). Nonetheless, the profound interconnection between culture itself and STEAM education remains somewhat underdeveloped (Fei-Fan, 2009), and the exploration of its educational value and assessment has not been extensively undertaken (Huo et al., 2020). Zhan Zehui et al. (2021) postulated that an education founded on the integration of disciplines to perpetuate exceptional traditional Chinese culture is indicative of STEAM education imbued with localized characteristics (C-STEAM) (Zhan et al., 2021). C-STEAM education transcends the mere incorporation of traditional cultural themes into extant STEAM curricula; it represents a highly integrated convergence of interdisciplinary knowledge within the framework of traditional culture. In this context, the fostering of humanistic ethos can be condensed and cultivated, nurturing students' cultural affiliation and comprehension. Anchored in the value framework and theoretical underpinnings of C-STEAM, Zhan et al. (2021) have expounded that C-STEAM education should manifest as a sequence of cogitation and practical activities deeply enmeshed within traditional cultural contexts. They introduced the 6C model of interdisciplinary integration education for cultural inheritance (C-STEAM) (Zhan et al., 2021).

Our research posits that C-STEAM education can comprehensively embody the interdisciplinary nature of STEAM education and unveil the metaphorical humanistic essence and educational value that underlie it. Nevertheless, the current stage necessitates substantial empirical substantiation to underpin this model. Hence, this study will primarily center around the C-STEAM design's 6C model for cultural inheritance, as delineated by Zhan Zehui et al (Zhan et al., 2021). The six teaching steps encompass cultural context perception, contextual experience, connotation comprehension, characteristic inquiry, artifact creation, societal connection, and reflective conclusion. These steps will serve as the cornerstone for exploring a novel teaching approach imbued with heightened educational significance. The application of the 6C model will be validated through experimental controls.

2.2 *Reverse engineering pedagogy*

Numerous practical research endeavors on the Reverse Engineering Teaching Method have been conducted both domestically and internationally. The team led by Professor Zhong Baichang adopted the concept of Reverse Engineering as a guiding theory in the exploration of a robotic teaching approach. They proposed four distinct Reverse Engineering Teaching Modes within the domain of robotic education, stemming from the dual perspectives of restoration experimentation and reconstruction experimentation. These modes are the Deconstruction Recovery Model, Troubleshooting Model, Element Minitrim Model, and Structural Innovation Model. Subsequently, they constructed the "Lantern Model" with the aim of nurturing students' interdisciplinary innovation prowes (Zhong et al., 2021). Several studies have demonstrated the pivotal role of this model in enhancing students' comprehension of knowledge, application capabilities, engineering cognition, and practical skills (Zhan et al., 2022). Li et al. applied the teaching model in interdisciplinary project teaching, and students' engineering thinking was improved (Li & Mei, 2023), and Zhong et al. (2022) also suggested that the model is applicable to different courses such as robotics education and creator education (Zhong et al., 2022).

Nevertheless, the implementation of STEAM education within higher education remains exceedingly limited. Within the realm of higher education, STEAM courses play a pivotal role in fostering students' information literacy, innovative mindset, and practical acumen (Huang & Liu, 2022). Consequently, the prospect of integrating the Reverse Engineering Teaching Method into higher education's STEAM curriculum warrants thorough examination. In summary, this research endeavor aims to amalgamate the reverse engineering "Lantern Model" devised by Professor Zhong Baichang's team. By infusing the methodologies and steps of deconstruction, restoration, error correction, and innovation into the process, the research aims to stimulate the augmentation and refinement of elements and structural innovation within subsequent projects. Additionally, it seeks to explore the potential for innovative cultural product development and the cultivation of students' creative thinking abilities through the practice of reverse engineering.

2.3 *Creative thinking and T-Shape talent innovative thinking training model*

Regarding the cultivation approach for nurturing Creative Thinking, Lin Chongde's extensive involvement in creative talent development over several years has led to the formulation of the equation "Creative Talents = Creative Thinking + Creative Personality" and the introduction of the T-Shape Talent Innovative Thinking Training Model. Within this model, the horizontal aspect of the T-Shape denotes the breadth of knowledge, while the vertical component signifies the depth of knowledge (Chongde & Weiping, 2012). Within this study, Professor Lin Chongde's T-Shape Talent Innovative Thinking Training Model serves as a foundational reference point for the construction of the proposed model. This construction incorporates the innovative thinking process of T-Shape Talents, wherein the horizontal dimension encapsulates the expansiveness of divergent thinking, and the vertical dimension captures the profundity of convergent thinking. Together, these components establish a concise framework for Creative Thinking, encompassing both divergence and convergence, thereby facilitating adept responses to teaching strategies. Depending on the specific orientation of Creative Thinking, it can be categorized into process-oriented (Nikkola et al., 2022), thinking-oriented (Sutarto et al., 2021), product-oriented (Gannon & Naidoo, 2020), and result-oriented (Avci & Durak, 2023) T-Shape thinking processes.

STEAM education notably enhances the cultivation of students' Creative Thinking. Wilson et al. (2021) conducted an empirical study on STEAM education and concluded that students engaged in STEAM courses exhibited heightened creativity, application aptitude, problem-solving skills, and collaboration proficiency, substantiating the effective enhancement of students' critical thinking and Creative Thinking (Wilson et al., 2021). According to Seo and Kim (2016), the interdisciplinary nature of STEAM education effectively nurtures students' hands-on capabilities, teamwork competence, and resilience. This environment encourages free expression of unique viewpoints, fosters mutual respect, stimulates thought during communication, and ignites Creative Thinking (Seo & Kim, 2016). The STEAM+ approach, which fuses STEAM with other disciplines, contributes significantly to the cultivation of students' Creative Thinking. Qualitative research by Rahmawati et al. (2019) demonstrated that students engaging in STEAM+ chemistry education displayed enhanced creative and critical thinking abilities (Rahmawati et al., 2019). Montes et al. (2022), through empirical research, affirmed that students exhibited elevated innovative thinking within STEAM+ physics learning contexts (Montes et al., 2022).

To synthesize, while various educational approaches, including STEAM+, effectively foster students' Creative Thinking, the potential impact of C-STEAM education on students' Creative Thinking remains uncharted territory.

Hence, this paper will center on the establishment of a C-STEAM Reverse Engineering Teaching Mode designed to propel students' Creative Thinking. To this end, the following hypotheses are proposed:

H1: The implementation of the C-STEAM Reverse Engineering Teaching Mode results in improved Creative Thinking among students.

2.4 *Cultural competence*

In 2018, the "21st Century Core Literacy 5C model" was officially introduced, wherein Cultural Competence stands as the linchpin of this framework (Yan et al., 2020). This model encompasses three essential facets: Cultural Understanding, Cultural Identity, and Cultural Practice. The cultivation of Cultural Competence bears immense significance as it fosters students' cultural literacy and nurtures their cultural identity, thereby propelling cultural inheritance and innovation. The proposition of Cultural Competence is inherently mirrored by the "C" within C-STEAM. C-STEAM education, marked by an intricate amalgamation of interdisciplinary knowledge within the tapestry of traditional culture, empowers students to delve into, appreciate, and scrutinize exceptional traditional Chinese culture comprehensively. It harnesses the realms of science, engineering, mathematics, and art to navigate the exploration and creation that brims with cultural significance. On this bedrock, we can foster and crystallize humanistic ideals while advancing students' Cultural Identity and Cultural Understanding. Sun et al. (2023) also explored the promotion of students' cultural heritage through STEAM education from a constructivist perspective and through cultural engagement in teaching practice (Sun et al., 2023). However, the application of Reverse Engineering Teaching Method in cultivating students' Cultural Competence remains an unexplored territory. Consequently, this study zeroes in on constructing the C-STEAM Reverse Engineering Teaching Mode to heighten students' Cultural Competence and posits the ensuing hypotheses:

H2: The utilization of the C-STEAM Reverse Engineering Teaching Mode results in enhanced Cultural Competence among students.

2.5 *The relationship between creative thinking and cultural competence*

The relationship between Creative Thinking and culture has garnered attention from a select group of scholars. Taylor and Wilson (2012) posit that culture, a vital manifestation of the societal milieu, encompasses both material prosperity and intangible wealth crafted by human endeavors throughout social and historical evolution (Taylor & Wilson, 2012). An inclination towards Creative Thinking is conceptually and empirically intertwined with a range of distinct attributes, notably cultural intelligence and a proclivity towards artistic creativity (Ashton et al., 2002; Kandler et al., 2014; Larson et al., 2002). This duality is explored from two perspectives. Firstly, it underscores the necessity of Creative Thinking within the realm of culture, highlighting how mass culture and art champion the cultivation of Creative Thinking (Purves, 1988). In the artistic domain, critical thought, artistry, imagination, practical creative thinking, and professional acumen are imperative, as are humanistic values and societal awareness (Feist, 1998;). Secondly, scholars have also explored ways of cultivating creative thinking from the perspective of the cultural classroom, emphasising the importance of cultural integration in the development of creative thinking skills (Okuno, 2023). Shabrina and Kuswanto (2018) devised an Android-assisted mobile physics learning program rooted in local batik craftsmanship to enhance students' Creative Thinking and problem-solving skills via experiential engagement (Shabrina & Kuswanto, 2018). Sumarni et al. (2020) adopted the STEM approach, coupling problem-based learning (PBL) with local cultural elements, to bolster Creative Thinking and problem-solving abilities. Outcomes demonstrated that students in the experimental group receiving STEM PBL with a cultural dimension exhibited progress within the mid-level category of creative thinking and problem-solving skills, in contrast to the control group that advanced within the low category (Sudarmin et al., 2020). In the pursuit of designing and implementing the C-STEAM Reverse Engineering Teaching Mode, careful attention must be directed towards fusing the cultural essence of C-STEAM education with the tenets of Reverse Engineering Teaching Method.

In light of these considerations, this study posits the ensuing hypothesis:

H3: The application of the Reverse Engineering Teaching Mode engenders a discernible impact of Creative Thinking on Cultural Competence.

2.6 *Engineering thinking*

Through an extensive review of domestic and international literature, Ling Ng Yuen posits that Engineering thinking signifies a cognitive framework forged by individuals during the execution of engineering tasks and stands as a notably pragmatic approach to planning-oriented thinking (Ling, 2018). Ling's developed process thinking evaluation framework encompasses four key facets: engineering decision thinking, engineering design thinking, engineering implementation thinking, and engineering evaluation thinking. This research acknowledges the lucidity and precision of this definition, utilizing it to conceive engineering thinking as a practical planning-oriented cognitive mode germane to accomplishing engineering endeavors.

In congruence with this understanding, Mu Haozhi and colleagues assert that Engineering thinking embodies scientific, artistic, and innovative attributes, aligning precisely with the quintessential characteristics of C-STEAM (Mu et al., 2022). Mohammed Akerdad and his team, in their research, unearthed that the application of Reverse Engineering Teaching Method through a visual drawing tool exerts a discernible influence on the cultivation of students' Engineering thinking (Akerdad et al., 2021). However, the impact of integrating the Reverse Engineering Teaching Method within the context of C-STEAM, aimed at nurturing students' Engineering thinking, remains a topic yet unexplored. Therefore, this study positions its focus on the establishment of a C-STEAM Reverse Engineering Teaching Model tailored to bolster students' Engineering thinking, positing the subsequent hypothesis:

H4: Implementation of the C-STEAM Reverse Engineering Teaching Mode culminates in enhanced Engineering thinking among students.

3. Conceptual framework

Cultural products themselves have the function of creating cultural context. The Reverse Engineering Teaching Method may have better teaching effect by allowing students to disassemble and micro-innovate on the basis of existing objects, rather than allowing students to build cultural cognition and cultural products from scratch. Therefore, based on the 6C model, this study integrates the "Lantern Model" of Reverse Engineering Teaching and the T-Shape Talent Innovative Thinking Training Model to build a C-STEAM Reverse Engineering Teaching Model for Creative Thinking (Figure 1).

This model allows students to decompose and restore cultural products in the process of context creation, and then reconstruct and create cultural products on the basis of understanding cultural connotations and exploring characteristics. Finally, it combines social promotion, summary evaluation and reflection, and finally realizes micro-innovation of cultural products. The teaching process mainly includes: (1) Cultural products trial and situational perception; (2) Decomposition and restoration of cultural artifacts; (3) Understanding of cultural connotation and exploring of characteristics; (4) Reconstruction and creation of cultural products; (5) Contact social promotion; (6) Summary, evaluation and reflection.

In this study, the T-Shape thinking process of divergent thinking and convergent thinking of the four directions corresponds to the creative thinking performance process of students in the teaching process, indicating the main thinking process of students in the teaching stage. Based on this, we determined the teaching strategy with strong operability and its specific application mode, namely, situational experience teaching strategy, heuristic teaching strategy, scaffolding teaching strategy, cooperative teaching strategy, inquiry teaching strategy, problem solving teaching strategy, technology realization teaching strategy, innovation and creation teaching strategy, multiple evaluation feedback strategy. The teaching strategy of C-STEAM Reverse Engineering Teaching Mode oriented to the cultivation of Creative Thinking is constructed.

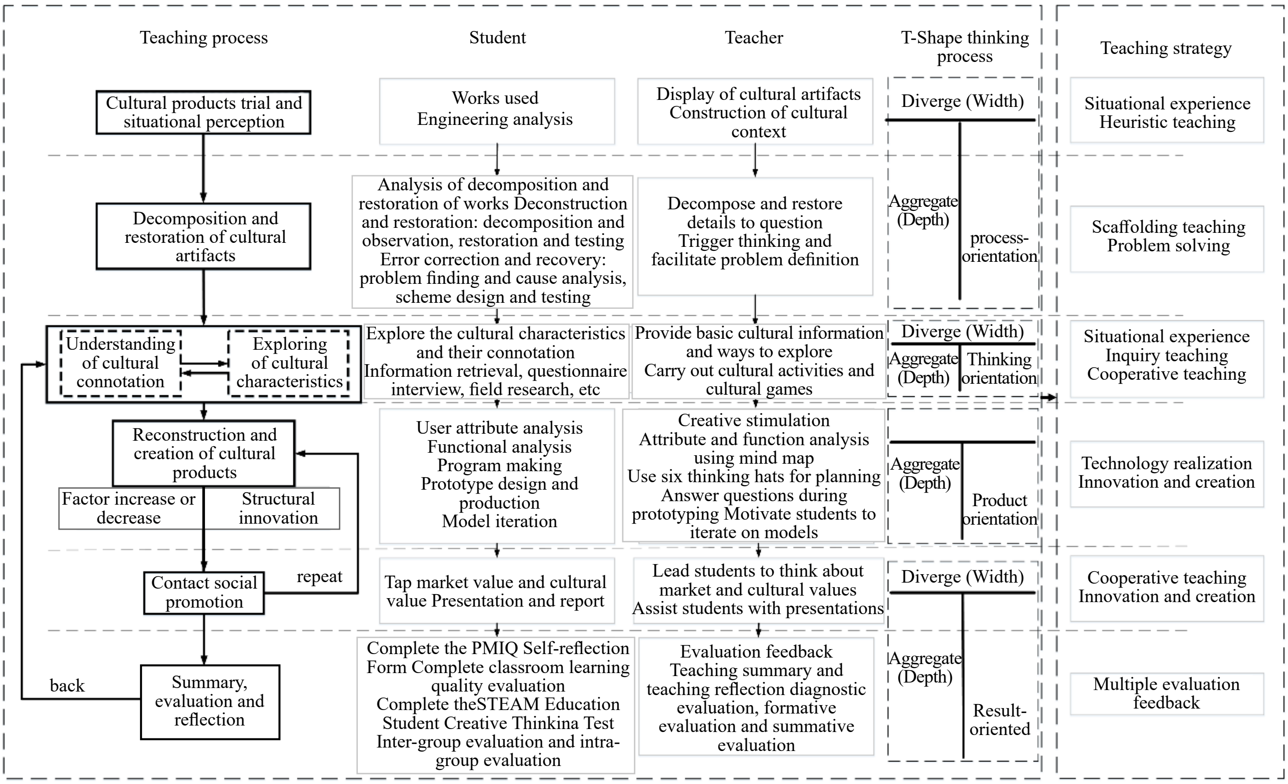


Figure 1. C-STEAM reverse engineering teaching model and strategy design for creative thinking

The model focuses on (1) Cultural products trial and situational perception, (2) Decomposition and restoration of cultural artifacts, and (4) Reconstruction and creation of cultural products.

Firstly, the teaching idea of reverse engineering is integrated, starting from the work, which is a work with different task forms and heterogeneous problems prepared by the teacher in advance and can inspire thinking. The teacher will display the cultural product in class, create a cultural context based on the product, and allow students to use the work and conduct engineering analysis in depth. Experience the appearance and functional characteristics of the works, and analyze its function from the engineering point of view.

Secondly, teachers can choose three types of tasks according to the teaching needs for students to decompose and restore cultural artifacts (Figure 2). According to the task attributes, the types of tasks can be divided into closed tasks, semi-open tasks and open tasks. Among the three task types, students need to conduct in-depth analysis and recovery of cultural artifacts (Table 1).

After cultural edification, students formally enter the reconstruction and creation of cultural products, which is the key part in the teaching process, and students' creative works and thinking outburst are mainly produced in this part. Students can reconstruct and create works from two aspects. One is to add or subtract elements. Students modify parameters or elements of works on the basis of existing products to promote divergence of thinking. The second is structural innovation, in which students transform or redesign the local structure of original works, services or rules from a multidisciplinary perspective to promote the divergence of thinking.

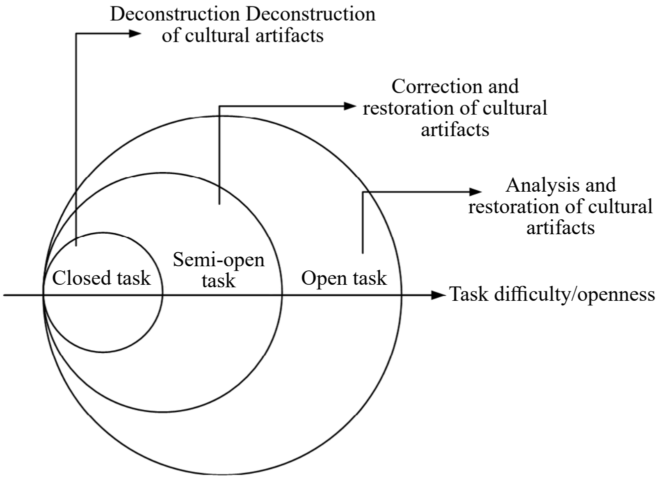


Figure 2. Task type selection structure diagram

Table 1. Task activity content

Task type	Task description
Task type 1: Deconstruction and restoration of cultural artifacts based on closed tasks.	The task for the students is to provide a complete and flawless product, and the students can recover it by analyzing the internal deconstruction features of the product.
Task type 2: Error correction and restoration of cultural artifacts based on semi-open task.	The task given to the student is to provide an incomplete or erroneous artifact, and the student needs to judge its completeness based on the knowledge construction, supplement the corresponding content, or find the erroneous content and correct it.
Task type 3: Analysis of cultural products based on open tasks.	Teachers assign an open task requirement according to the teaching products. Students can analyze the structure and content of the products, but they are not limited to the cultural products provided by teachers. Students can use their imagination to create the products according to their existing knowledge and experience.

4. Methods

4.1 *Research design*

Since this is the first time reverse engineering has been integrated into C-STEAM education, a pilot experiment (Study 1) is conducted before a formal experiment (Study 2). Both studies used quasi-experimental designs to try to validate the C-STEAM Reverse Engineering Teaching mode and compare the impact of Forward Project-based Pedagogy (FPP) with Reverse Engineering Pedagogy (REP). Both studies used essentially the same measurement tools, but the procedures and teaching materials in Study 2 were modified based on reflections in Study 1.

In this study, FPP and REP were used in experimental group and control group, respectively. The intervention of FPP followed the 6C model proposed by Zhan Zehui (Zhan et al., 2021), while the intervention of REP followed the C-STEAM Reverse Engineering Teaching mode proposed in this study. This study examined two interventions for students of the educational technology elective “Design Thinking and STEAM Education” in the second year of undergraduate studies. The following table shows the teaching steps for these two teaching interventions (Table 2).

Table 2. Teaching intervention steps of FPP and REP

Group	Method	Teaching steps
Control group	FPP	(1) Contextual Experience; (2) Connotation Comprehension; (3) Characteristic Inquiry; (4) Create Artifact; (5) Connect Society; (6) Conclusion Reflection.
Experimental group	REP	(1) Cultural products trial and situational perception; (2) Decomposition and restoration of cultural artifacts; (3) Understanding of cultural connotation and exploring of characteristics; (4) Reconstruction and creation of cultural products; (5) Contact social promotion; (6) Summary, evaluation and reflection.

4.2 *Measures*

This study explores the effects of FPP and REP on students' Creative Thinking, Cultural Competence and Engineering Thinking. This study utilized an online questionnaire survey to assess the Creative Thinking of students in STEAM education, as well as to measure Cultural Competence, and Engineering thinking. The assessment was conducted before and after implementing the C-STEAM Reverse Engineering Teaching Mode with students in FPP group and REP group.

After collecting the data, it underwent cleaning, statistical analysis, and processing. Firstly, an independent sample t-test was employed to examine if there were significant differences in learning outcomes between the two groups of research objects. Secondly, paired sample t-tests were used to compare the effects of the two teaching intervention methods on students' Creative Thinking, Cultural Competence, and Engineering thinking to determine if REP students experienced effective enhancements, thereby validating the effectiveness of the C-STEAM Reverse Engineering Teaching Mode. Lastly, through correlation and regression analysis, an attempt was made to identify the relationship between Creative Thinking and Cultural Competence.

The creative thinking measurement tool is derived from the student creative thinking assessment index system in STEAM education. It is a development of the PISA 2021 creative thinking assessment, emphasizing students generating new ideas in context, evaluating and reflecting on new ideas, and iterating ideas until satisfactory results are achieved. The C-STEAM Reverse Engineering teaching mode proposed in this study also emphasizes the creation of cultural contexts and the iterative creation of cultural products, making the measurement tool suitable for this study.

The Cultural Competence measurement tool is based on the "Attitude-Skills-Knowledge" model, which has been validated through empirical research. The 'C' in C-STEAM emphasizes the integration of the requirements for Cultural Competence from the 5C model of 21st-century core literacy, forming dimensions in Cultural Understanding, Cultural Identity, and Cultural Practice. Therefore, this measurement tool is suitable for this study.

The Engineering Thinking measurement tool originates from the engineering thinking process evaluation experiment, which requires students to apply critical and creative thinking in engineering practice, thus forming engineering decision thinking, engineering design thinking, engineering implementation thinking, and engineering evaluation thinking. This study focuses on cultivating students' creative thinking and is also conducted in interdisciplinary engineering practices within STEAM, hence making the measurement tool applicable to this study.

Tools for pre-test and post-test are shown in the following table (Table 3). It is mainly a five-dimensional Likert scale. All the students completed the pre-test and the post-test separately.

To address the limitations and biases in data collection methods and measurement tool selection, the following measures have been taken in this study: First, to ensure the authenticity of the data, data collection is conducted within a brief period before and after the experiment under teacher supervision. Second, to ensure the operability of the data, the measurement tools all uniformly use the Likert 5 point scale. Third, to ensure the reliability and validity of the measurement tools, priority is given to selecting measurement tools that align well with the study, have high authority, or have been validated through empirical research.

Table 3. Tools for pre-test and post-test

Measures	Dimensions	Source	Cronbach's alpha	Remarks
Creative Thinking	Generate diverse ideas (fluency, flexibility, comprehensiveness), generate creative ideas (novelty, value, feasibility), generate precise ideas (accuracy, rationality, logicality, concreteness), evaluate and improve ideas (evaluate ideas, improve ideas). In the pre-experiment test, all 37 questions	(Lin et al., 2022)	0.993 (Source: from the developers)	In the pre-experiment test, A1 Fluency and A2 Flexibility reference Torrance speech test were adapted into 6 text questions, and the number and types of ideas generated by students were collected and counted
Cultural Competence	Cultural understanding, cultural identity and cultural practice, all 7 questions	(Leung & Cheung, 2013), (Yan et al., 2020)	0.775 (Source: from the pretest in the pilot study)	-
Engineering Thinking	Engineering decision thinking, engineering design thinking, engineering implementation thinking and engineering evaluation thinking, all 7 questions	(Ling, 2018)	0.869 (Source: from the pretest in the pilot study)	-

4.3 *Study 1: the pilot study*

In the pre-experiment, a total of 30 second-year undergraduates of educational technology in South China Normal University were determined as the research objects. Education technology itself is an interdisciplinary field that combines knowledge from disciplines such as education and computer science. The research objects have acquired basic professional knowledge, including educational psychology, principles of instructional design, computer technology, and possess certain teamwork skills and innovation awareness. They can utilize their expertise, combine it with technologies such as computer science, collaborate as a team, and innovatively design a C-STEAM course suitable for the research design of this study. According to the pre-test results and the guarantee of their level, the students were randomly divided into two groups: 15 in the FPP group (control group) and 15 in the REP group (experimental group). The students in the group are divided into 5 learning groups on average, so the experimental group and the control group each have 3 learning groups, a total of 6 learning groups. The experiment lasted for three months from March to June 2021. This experiment is planned to be conducted once a week, each time about 1 lesson (60 minutes), a total of 8 hours, for 8 weeks.

Table 4. The reliability and validity of the questionnaire were measured before and after the pre-experiment

Reliability and validity of pre-test			
	Cronbach's alpha	KMO	Sig.
Creative Thinking	0.941	0.751	0.00
Cultural Competence	0.775	0.631	0.00
Engineering Thinking	0.869	0.752	0.00
Post-test reliability and validity			
Creative Thinking	0.972	0.838	0.00
Cultural Competence	0.693	0.612	0.00
Engineering Thinking	0.866	0.801	0.00

Reliability and validity tests were conducted on the pre and post tests of the two groups (Table 4), and the results showed that Cronbach's alpha was greater than 0.65, indicating good internal consistency, and KMO measures were greater than 0.6, Sig. Value 0.000 < 0.05, the data is suitable for validity factor analysis. Based on the above analysis results, this study believes that the test before and after the experiment has good reliability and validity, and the survey data is real and credible.

Through the pilot study, it is found that students need to strengthen their Creative Thinking, Cultural Competence and Engineering Thinking. In terms of Creative Thinking, students have no significant improvement in Generate Diverse Ideas, Generate Creative Ideas and Evaluate and Improve Ideas. Therefore, it is necessary to strengthen the guidance of students' divergent thinking, guide students to think from multiple angles and use methods to evaluate and improve ideas. In terms of Cultural Competence, students have not significantly improved in Cultural Practice, so it is necessary to choose appropriate cultural carriers and strengthen the cultivation of students' hands on ability. In terms of Engineering Thinking, students' performance improved significantly, so they could develop progressive projects and increase technical difficulty according to students. In addition, according to the Reverse Engineering task type, the experimental group is subdivided into three task type groups in the formal experiment, including the closed task group, the semi-open task group and the open task group. Specific measures are shown below (Table 5).

Table 5. Specific measures for the pilot study reflection and improvement

Focus		Concrete measures
Creative Thinking	Focus on students' ability to A Generate Diverse Ideas, A1 Fluency, A2 Flexibility, A3 Comprehensiveness, B Generate Creative Ideas, B1 Novelty, B3 Feasibility, C2 Rationality, D Evaluate and Improve Ideas, D1 Evaluate Ideas.	Use a variety of design thinking divergence tools to guide students to divergent thinking; The use of user attribute analysis to stimulate students to think and produce more views, and guide students to think from a variety of perspectives; Through the method of six thinking caps, students learn the way of thinking of design thinking in the activity.
Cultural Competence	Strengthen the promotion of cultural practice literacy, fully internalize the theory to promote the occurrence of practice.	Use Luban lock hands on production link to let students dig deeply into the connotation and characteristics of mortise and tenon culture. Choosing "chair" with strong design freedom as the carrier of mortise and tenon culture can not only ensure the feasibility of decomposition and restoration, but also ensure the freedom of students' creation, which can be combined with artificial intelligence module for multi-functional design.
Engineering Thinking	The task difficulty is moderate and progressive.	Allow students to fully learn and understand the Mind + AI programming project through three subdivided progressive projects. To confirm the technical difficulty in advance, the creation of cultural products requires at least two or more mortise and tenon structures and two or more artificial intelligence programming functions.
Task Type	The experimental group is subdivided into three task type groups, including closed task group, semi-open task group and open task group.	The closed task group needs to analyze the deconstruction and restoration of the given works. The semi-open task group is required to conduct error correction and recovery analysis for the given work; The open task team is required to make structural observations based on the given work, and on this basis generate new conceptual ideas.

4.4 *Study 2: the formal study*

4.4.1 *Experimental object*

In the formal study, a total of 60 second-year undergraduates majoring in educational technology in South China Normal University were determined to be the subjects of the study. The background and characteristics of the experimental object in the formal study are consistent with those in the pilot study, but the individuals and quantity of the experimental object in the formal study are different from the pilot study. According to the pre-test results and the guarantee of their level, the students were randomly divided into two groups: 30 in the FPP group (control group) (11 boys and 19 girls) and 30 in the REP (experimental group) (10 boys). In the group, the students were divided into an average of 5 study groups, so the experimental group and the control group each had 6 study groups, a total of 12 study groups.

Pre-test was carried out before the experiment, and the results showed that the two groups scored well in Creative Thinking ($F(0.878) = 0.353$, $p = 0.841$), Cultural Competence ($F(0.107) = 0.745$. $p = 0.638$) and Engineering Thinking ($F(0.470) = 0.496$, $p = 0.478$) were not significantly different, indicating that the students' starting levels were basically the same.

4.4.2 *Experimental plan and procedure*

The experiment will last for five months from September 2021 to January 2022. This experiment is planned to be conducted once a week with about 3 lessons (120 minutes) each time, totaling 32 hours for 16 weeks (Table 6).

Table 6. The formal study weekly lesson plans and theme

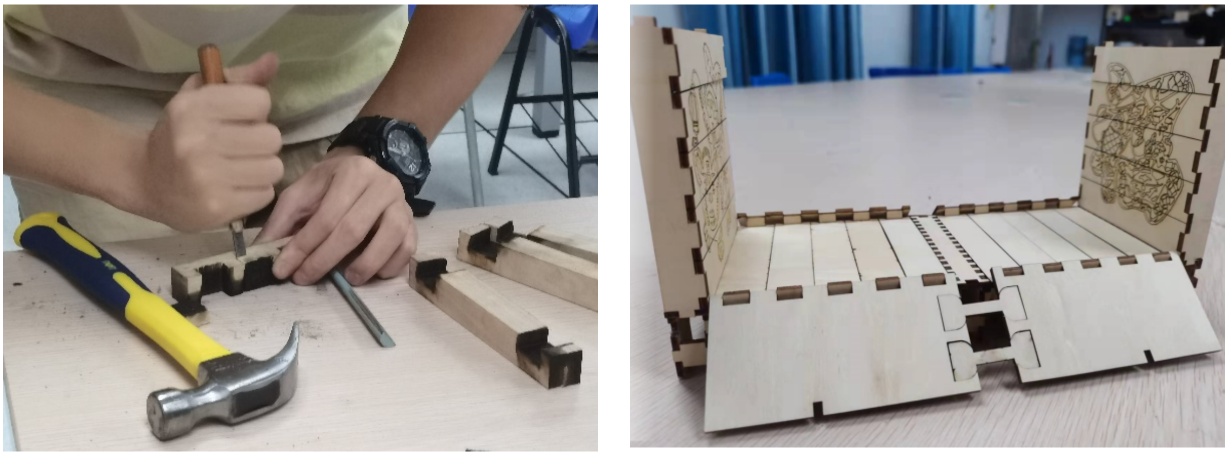
Week	Teaching process	Main content
Week 1	An overview of design thinking and STEAM education	Course introduction, identify study groups, determine learning objectives and content, introduce learning methods and course evaluation methods, provide learning resources and learning recommendations, and provoke students to think about the connection between design thinking and STEAM education.
Week 2	Introduction to STEAM Education	With core literacy as the orientation, learn the basic connotation and classification of STEAM education as an interdisciplinary project-based learning, including the following aspects: the concept, connotation and characteristics of STEAM education; Domestic and international development of STEAM education; STEAM education research and application status; STEAM education case interpretation and discussion.
Week 3	C-STEAM: Models and cases	Learn the basic connotation and four value orientations of C-STEAM education concept; Study the "6C" teaching mode of C-STEAM education and discuss its application in depth; C-STEAM teaching case teaching content analysis.
Week 4	C-STEAM Teaching Design (1)	Understand the concept and basic principle of instructional design; Consider the basic elements of instructional design; Related models and main contents of learning instructional design; Practice assignment 1: Teaching design of integrating intangible cultural heritage into science subject teaching.
Week 5	C-STEAM Teaching Design (2)	Teaching design case study; Practice assignment 2: Teaching design of integrating intangible cultural heritage into the teaching of liberal arts.
Week 6	Design thinking and basic application methods	To understand the concept, connotation and characteristics of design thinking and the history and present situation of design thinking; Recognize the "T" qualities of design thinkers and the 5 basic steps of design thinking. Understand the concept, connotation and characteristics of design thinking; Understand the history and current situation of design thinking; Master the steps and application methods of design thinking.
Week 7	Interpretation and practical application of design thinking application model	Interpret the basic methods and tools of design thinking, including user attribute analysis, requirement understanding, problem definition, thinking divergence, prototyping, model iteration and result release; Finally, the relationship between artificial intelligence and design is discussed. Learn the basic methods of user attribute analysis; Learn the need to understand, understand and apply "empathy"; Master the method of problem definition; Master the method of prototype design; Understand the purpose and common methods of thinking divergence; Learn to iterate and test models.
Week 8	3D printing, laser cutting	Master certain laser cutting and 3D printing technology; Able to use laser cutting and 3D printing technology to make product prototypes.
Week 9	Open source hardware and graphical programming	Learn the basic functions of open source hardware; Familiar with Mind + graphical programming software; Learn to use open source hardware and graphical programming for simple project learning; Learn the basic ideas and basic applications of artificial intelligence modules.
Week 10	Mortise and tenon culture	Sensing mortise and tenon structure sensing; Understand mortise and tenon characteristics; Compare ancient and modern mortise and tenon culture; Learn the case of mortise and tenon culture into the campus.
Week 11	Group project practice: teaching plan and teaching project design and development	Cultural products trial and situational perception Cultural artifacts decomposition and deconstruction recovery/error correction recovery.
Week 12		Understanding of cultural connotation and exploring of characteristics.
Week 13		Reconstruction and creation of cultural products.
Week 14		
Week 15		Contact social promotion (Group project report and comment).
Week 16		Summary, evaluation and reflection (course review and summary).

In terms of teaching intervention methods, for this research experiment, we selected C-STEAM Reverse Engineering Teaching Mode oriented to Creative Thinking as the intervention means for the experimental group, and C-STEAM 6C Forward Project-based Pedagogy as the intervention means for the control group. Different from the pilot study, in the formal study, students were divided into closed task groups, semi-open task groups and open task groups, with 10 people in each group, in combination with different task requirements, so as to better distinguish which task type is more conducive to the improvement of the application effect of the C-STEAM Reverse Engineering Teaching Mode for the cultivation of Creative Thinking. In addition, after the summary and reflection of the pilot study, the intervention methods of the REP group were also adjusted and optimized. In order to ensure that the original level of the two groups was at the same level, the two groups were pre-tested and the teaching intervention was implemented for the two groups (Table 7).

Table 7. The formal study process design

Pre-test: Creative Thinking test, Cultural Competence test, Engineering Thinking test			
FPP Group (Control group)		REP Group (Experimental group)	
Teaching process	intervene	Teaching process	intervene
Contextual Experience	By creating cultural context experience, teachers let students have a preliminary understanding of culture.	Cultural products trial and situational perception	Teachers create cultural context experience and ask questions to inspire students to think, and students use works and engineering analysis to promote divergent thinking.
Connotation Comprehension	Teachers provide students with worksheets and guide students to cooperate to complete cultural connotation understanding.	Decomposition and restoration of cultural artifacts	The teacher provided the scaffolding through the students' worksheets to guide the closed task group to deconstruct and restore the cultural artifacts, decompose and observe the works, and ask questions about the restoration details; Guide the semi-open task group to correct and restore cultural artifacts, encourage students to find problems and cause analysis, trigger thinking and problem definition, and promote thinking aggregation.
Characteristic Inquiry	Teachers provide students with worksheets and guide students to collaborate on cultural characteristics research.	Understanding of cultural connotation and exploring of characteristics	The teacher guides the students to experience the mortise and tenon cultural situation through Luban lock making, and the teacher uses the mortise and tenon application program for game competition, collaboration and exploration.
Create Artifact	Teachers guide students to conduct needs analysis and program formulation, system implementation and testing.	Reconstruction and creation of cultural products	The teacher organizes students to use mind mapping to analyze user attributes and work functions, and uses the method of six thinking caps to make plans to promote the realization of technology. The teacher guides students to innovate and create works in the two dimensions of factor addition and subtraction and structural innovation, and encourages students to iterate models in the process.
Connect Society	Guide students to think about the value of the work and try to promote it, so that students can get reflection in the collaboration.	Contact social promotion	Guide students to think about the market value and cultural value of the work and try to promote it, let students get reflection in the collaboration, and put forward the second iteration feedback in the student demonstration report to promote innovative creation.
Conclusion Reflection	Teachers summarize the evaluation feedback, conduct teaching reflection, and students conduct inter-group evaluation and self-evaluation.	Summary, evaluation and reflection	Teachers summarize the evaluation feedback, conduct teaching reflection, and students conduct inter-group evaluation and self-evaluation, among which the production of the work is required to reflect at least two mortise and tenon structures and two or more artificial intelligence programming functions.
Post-test: Creative Thinking test, Cultural Competence test, Engineering Thinking test			

Figure 3 and Figure 4 show that students learn differently in FPP and REP interventions. In the FPP, as shown in Figure 3, students first perceive the Contextual Experience and Connotation Comprehension, then Create Artifact after Characteristic Inquiry, and finally Connect Society and Conclusion Reflection. In this case, they are guided step by step by the teacher. However, in REP, as shown in Figure 4, students start from the Cultural products trial and situational perception, and then carry out Decomposition and restoration of cultural artifacts, then carry out Understanding of cultural connotation and exploring of characteristics, then carry out Reconstruction and creation of cultural products, and finally Contact social promotion and Summary, evaluation and reflection. In this case, they form their own works by deconstructing teachers' works in reverse.



(a) Students gradually learn the mortise and tenon culture (b) Student work

Figure 3. FPP intervention

(a) Teachers display cultural artifacts (b) Student work

Figure 4. REP intervention

5. Results: study 2

According to statistics, a total of 60 students participated in the post-test, with 60 valid papers. SPSS 25.0 was used to analyze the data of the post-test results. The statistical methods were independent sample T-test, paired sample T-test, correlation analysis and regression analysis.

Independent sample T-test was carried out on the two groups after the test, and the results showed that the two groups achieved high performance in Creative Thinking ($F(0.006) = 0.938$, $p = 0.719$), Cultural Competence ($F(0.216) = 0.644$, $p = 0.391$) and Engineering Thinking ($F(0.626) = 0.432$, $p = 0.547$) were not significantly different. Therefore, it is possible that both groups have certain improvement after intervention. The paired sample T-test is conducted below to compare the differences before and after the two groups respectively.

It should be noted that all 90 participants in this study have agreed to participate in the whole experiment process, including data collection and analysis. we de-identified the personal information of the subjects to ensure data privacy.

5.1 *Creative thinking (Table 8)*

5.1.1 *A generate diverse ideas (A1 Fluency, A2 Flexibility, A3 Comprehensiveness)*

In the post-test, there are differences in the number of items in A1 Fluency (F(0.303) = 0.584, p = 0.432) and A2 Flexibility (F(0.414) = 0.523, p = 0.849) between the control group and the experimental group, but there is no significant difference. After the paired sample T-test, the control group (Mean = 0.356, p = 0.221) and the experimental group (Mean = 0.289, p = 0.337) have p values greater than 0.05 of A3 Comprehensiveness, and the improvement effect is not significant.

5.1.2 *B generate creative ideas (B1 Novelty, B2 Value, B3 Feasibility)*

After the paired sample T-test, the control group (Mean = 0.427, P = 0.055) and the experimental group (Mean = 0.507, p = 0.101) have p values greater than 0.05 of the whole of B Generate Creative Ideas, and the improvement effect is not significant. The control group (mean = 0.633, p = 0.003) and the experimental group (mean = 0.533, p = 0.040) have p values less than 0.05 of the B1 Novelty, and the improvement effect is significant. The control group (mean = 0.533, P = 0.005) and the experimental group (mean = 0.800, p = 0.000) have p values less than 0.05 of the B2 Value, and the improvement effect is significant. The control group (mean = 0.192, P = 0.131) and the experimental group (mean = 0.267, P = 0.223) have p values greater than 0.05 of the B3 Feasibility, and the improvement effect is not significant.

5.1.3 *C generate precise ideas (C1 Accuracy, C2 Rationality, C3 Logicality, C4 Concreteness)*

After the paired sample T-test, the control group (mean = 0.319, p = 0.105) have p values greater than 0.05 of the whole of C Generate Precise Ideas, and the improvement effect is not significant. The experimental group (mean = 0.511, P = 0.014) have p values less than 0.05 of the whole of C Generate Precise Ideas, and the improvement effect is significant. The control group (mean = 0.444, p = 0.004) and the experimental group (mean = 0.578, p = 0.002) have p values less than 0.05 of the whole of C1 Accuracy, and the improvement effect is significant. The control group (mean = 0.256, p = 0.140) have p values greater than 0.05 of the C2 Rationality, and the improvement effect is not significant. The experimental group (mean = 0.511, p = 0.007) have p values less than 0.05 of the C2 Rationality, and the improvement effect is significant. The control group (mean = 0.378, P = 0.020) and the experimental group (mean = 0.522, p = 0.006) have p values less than 0.05 of the whole of C3 Logicality, and the improvement effect is significant. The control group (mean = 0.322, p = 0.155) have p values greater than 0.05 of the C4 Concreteness, and the improvement effect is not significant. The experimental group (mean = 0.500, p = 0.029) have p values less than 0.05 of the C4 Concreteness, and the improvement effect is significant.

5.1.4 *D evaluate and improve ideas (D1 Evaluate Ideas, D2 Improve Ideas)*

After the paired sample T-test, the control group (mean = 0.250, P = 0.213) and the experimental group (mean = 0.333, p = 0.101) have p values greater than 0.05 of the whole of D Evaluate and Improve Ideas, and the improvement effect is not significant. The control group (mean = 0.244, P = 0.215) and the experimental group (mean = 0.344, p = 0.158) have p values greater than 0.05 of the whole of D1 Evaluate Ideas, and the improvement effect is not significant. The control group (mean = 0.250, p = 0.211) have p values greater than 0.05 of the D2 Improve Ideas, and the improvement effect is not significant. The experimental group (mean = 0.333, p = 0.044) have p values less than 0.05 of the D2 Improve Ideas, and the improvement effect is significant.

Overall, there was a significant increase in Creative Thinking across multiple dimensions. Specifically, significant disparities emerged in B1 Novelty, B2 Value, C Generate Precise Ideas, C1 Accuracy, C2 Rationality, C3 Logicality, C4 Concreteness, and D2 Improve Ideas. These results verify H1: The implementation of the C-STEAM Reverse Engineering Teaching Mode results in improved Creative Thinking among students, and affirm the effectiveness of the proposed teaching mode in improving students' Creative Thinking.

Table 8. Formal experimental Creative Thinking paired sample T-test

Paired sample T-Test (Creative Thinking)										
			FPP Group (Control group)				REP Group (Experimental group)			
Dependent variable			Mean	Standard deviation	t	Sig.	Mean	Standard deviation	t	Sig.
Creative Thinking	A Generate Diverse Ideas	A1 Fluency	-	-	-	-	-	-	-	-
		A2 Flexibility	-	-	-	-	-	-	-	-
		A3 Comprehensiveness	-0.356	0.762	-2.652	0.221	-0.289	0.761	-2.107	0.337
		A Total	-0.356	0.762	-2.652	0.221	-0.289	0.761	-2.107	0.337
	B Generate Creative Ideas	B1 Novelty	-0.633	0.893	-3.845	0.003	-0.533	0.938	-3.108	0.040
		B2 Value	-0.533	0.880	-3.352	0.005	-0.800	0.998	-4.391	0.000
		B3 Feasibility	-0.192	0.685	-1.428	0.131	-0.267	0.886	-1.669	0.223
		B Total	-0.427	0.806	-2.730	0.055	-0.507	0.935	-2.917	0.101
	C Generate Precise Ideas	C1 Accuracy	-0.444	0.785	-3.113	0.004	-0.578	0.907	-3.489	0.002
		C2 Rationality	-0.256	0.902	-1.543	0.140	-0.511	0.905	-3.118	0.007
		C3 Logicality	-0.378	0.779	-2.660	0.020	-0.522	0.788	-3.831	0.006
		C4 Concreteness	-0.322	0.899	-2.017	0.155	-0.500	1.011	-2.769	0.029
		C Total	-0.319	0.860	-2.073	0.105	-0.511	0.902	-3.240	0.014
	D Evaluate and Improve Ideas	D1 Evaluate Ideas	-0.244	0.773	-1.698	0.215	-0.344	0.754	-2.442	0.158
		D2 Improve Ideas	-0.256	0.683	-2.138	0.211	-0.322	0.833	-2.151	0.044
		D Total	-0.250	0.728	-1.918	0.213	-0.333	0.794	-2.296	0.101
	Total		-0.356	0.800	-2.412	0.111	-0.460	0.878	-2.868	0.089

5.2 *Cultural competence*

After the paired sample T-test (Table 9), the control group (mean = 5.967, p = 0.000) and the experimental group (mean = 5.767, p = 0.000) have p values less than 0.05 of the whole of Cultural Competence, and the improvement effect is significant. It is worth noting that the standard deviation of Cultural Competence of the experimental group is 4.695, which is lower than that of the control group, which is 5.524. Therefore, it can be shown that the smaller the dispersion degree of the values of Cultural Competence of the experimental group, the more concentrated and stable they are. The control group (mean = 4.467, P = 0.000) and the experimental group (mean = 4.800, p = 0.000) have p values less than 0.05 of the Cultural Understanding, and the improvement effect is significant. The control group (mean = 1.000, P = 0.002) and the experimental group (mean = 0.700, p = 0.020) have p values less than 0.05 of the Cultural Identity, and the improvement effect is significant. The control group (mean = 0.500, P = 0.181) and the experimental group (mean = 0.267, p = 0.234) have p values greater than 0.05 of the Cultural Practice, and the improvement effect is not significant.

Concerning Cultural Competence, noteworthy trends emerged in the REP group's performance. It is verified that the application of H2: The utilization of the C-STEAM Reverse Engineering Teaching Mode results in enhanced Cultural Competence among students. Notably, substantial disparities were evident in the overall pre-test and post-test, as well as in Cultural Understanding and Cultural Identity, while no significant differences manifested in Cultural Practice.

Table 9. Formal experimental cultural competence paired sample T-test

Paired sample T-test (Cultural competence)									
		FPP Group (Control group)				REP Group (Experimental group)			
Dependent variable		Mean	Standard deviation	t	Sig.	Mean	Standard deviation	t	Sig.
Cultural Competence	Cultural Understanding	-4.467	3.126	-7.825	0.000	-4.800	3.210	-8.191	0.000
	Cultural Identity	-1.000	1.597	-3.429	0.002	-0.700	1.557	-2.463	0.020
	Cultural Practice	-0.500	1.996	-1.372	0.181	-0.267	1.202	-1.216	0.234
	Total	-5.967	5.524	-5.916	0.000	-5.767	4.695	-6.727	0.000

5.3 *The relationship between creative thinking and cultural competence*

5.3.1 *Correlation analysis*

In this study, Pearson product difference correlation analysis method was used to test the correlation between Creative Thinking and Cultural Competence (Table 10).

As can be seen from the above table, Creative Thinking is highly positively correlated with overall Cultural Competence, as well as Cultural Understanding and Cultural Practice (P < 0.01), but there was no significant correlation between Creative Thinking and Cultural Identity.

Table 10. Correlation between creative thinking and cultural competence

	Correlation								
	A Generate Diverse Ideas	B Generate Creative Ideas	C Generate Precise Ideas	D Evaluate and Improve Ideas	Creative Thinking	Cultural Understanding	Cultural Identity	Cultural Practice	Cultural Competence
A Generate Diverse Ideas	1	-	-	-	-	-	-	-	-
B Generate Creative Ideas	0.775**	1	-	-	-	-	-	-	-
C Generate Precise Ideas	0.754**	0.888**	1	-	-	-	-	-	-
D Evaluate and Improve Ideas	0.782**	0.882**	0.823**	1	-	-	-	-	-
Creative Thinking	0.892**	0.955**	0.932**	0.937**	1	-	-	-	-
Cultural Understanding	0.641**	0.562**	0.530**	0.526**	0.609**	1	-	-	-
Cultural Identity	0.282*	0.154	0.144	0.304*	0.238	0.379**	1	-	-
Cultural Practice	0.428**	0.397**	0.465**	0.503**	0.481**	0.526**	0.588**	1	-
Cultural Competence	0.568**	0.467**	0.474**	0.550**	0.554**	0.809**	0.789**	0.846**	1

**. At 0.01 level (two-tailed), the correlation was significant; *. At level 0.05 (two-tailed), the correlation was significant

5.3.2 *Regression analysis*

According to the results of the correlation table, regression analysis is further used to investigate the influence of various dimensions of Cultural Competence on Creative Thinking (Table 11).

Table 11. Regression analysis results of creative thinking and cultural competence

Dependent variable	Independent variable	Beta	B	t	Sig.	R square	F	VIF	Durbin watson
Creative Thinking	Cultural Competence	0.550	8.934	5.014	0.000	0.302	25.135	1.000	2.126
	Cultural Understanding	0.461	5.361	3.879	0.000	0.394	18.503	1.383	2.111
	Cultural Practice	0.247	3.635	2.241	0.046	0.394	18.503	1.383	2.111
A Generate Diverse Ideas	Cultural Understanding	1.036	0.577	4.806	0.000	0.423	13.677	1.397	2.203
	Cultural Identity	-0.033	-0.016	-0.124	0.902	0.423	13.677	1.544	2.203
	Cultural Practice	0.305	0.134	0.976	0.333	0.423	13.677	1.827	2.203
B Generate Creative Ideas	Cultural Understanding	7.576	0.487	3.812	0.000	0.326	13.773	1.383	1.967
	Cultural Practice	2.679	0.136	1.063	0.292	0.326	13.773	1.383	1.967
C Generate Precise Ideas	Cultural Understanding	4.601	0.373	2.886	0.006	0.310	12.812	1.383	1.749
	Cultural Practice	4.080	0.261	2.019	0.048	0.310	12.812	1.383	1.749
D Evaluate and Improve Ideas	Cultural Understanding	5.181	0.353	2.804	0.007	0.364	10.699	1.397	2.367
	Cultural Identity	-0.597	-0.035	-0.261	0.795	0.364	10.699	1.544	2.367
	Cultural Practice	6.677	0.359	2.493	0.016	0.364	10.699	1.827	2.367

It can be seen from the table that Cultural Competence contributes to the interpretation of Creative Thinking, and Cultural Competence can explain 30.2% of Creative Thinking, thus Creative Thinking = 31.373 + 8.934* Cultural Competence; Cultural Understanding and Cultural Practice contribute to the explanation of Creative Thinking, and can explain 39.4% of Creative Thinking; Cultural Understanding contributes to the interpretation of A Generate Diverse Ideas and can explain 42.3% of A Generate Diverse Ideas, while Cultural Identity and Cultural Practice do not contribute to the interpretation of A Generate Diverse Ideas. Cultural Understanding contributes to the explanation of B Generate Creative Ideas and can explain 32.6% of B Generate Creative Ideas, while Cultural Practice does not contribute to the explanation of B Generate Creative Ideas. Both Cultural Understanding and Cultural Practice contribute to the interpretation of C Generate Precise Ideas and can explain 31% of C Generate Precise Ideas. Cultural Understanding and Cultural Practice contributed to the interpretation of D Evaluate and Improve Ideas, and could explain 36.4% of D Evaluate and Improve Ideas, while Cultural Identity did not contribute to the interpretation of D Evaluate and Improve Ideas.

In general, it can be proved that hypothesis H3: The application of the Reverse Engineering Teaching Mode engenders a discernible impact of Creative Thinking on Cultural Competence.

5.4 *Engineering thinking*

After the paired sample T-test (Table 12), the control group (mean = 5.800, P = 0.000) and the experimental group (mean = 4.833, p = 0.000) have p values less than 0.05 of the whole of Engineering thinking, and the improvement effect is significant. So we can prove H4: Implementation of the C-STEAM Reverse Engineering Teaching Mode culminates in enhanced Engineering thinking among students.

Table 12. Formal experimental engineering thinking paired sample T-test

	Paired sample T-test (Engineering thinking)							
	FPP Group (Control group)				REP Group (Experimental group)			
Dependent variable	Mean	Standard deviation	t	Sig.	Mean	Standard deviation	t	Sig.
Engineering thinking	-5.800	5.095	-6.235	0.000	-4.833	4.969	-5.327	0.000

6. Discussion

Combining the results of Study 1 and Study 2, we come to the following conclusions and discussions. Including four aspects, the first is REP has a significant improvement in the C2 Rationality, C4 Concreteness, C Generate Precise Ideas and D2 Improve Ideas of students' Creative Thinking. The second is REP has a significant improvement in Cultural Understanding and Cultural Identity of students' Cultural Competence, but no significant improvement in Cultural Practice. Thirdly, under REP, students' Creative Thinking has an impact on Cultural Competence. Finally, REP can significantly improve students' Engineering Thinking. This will be discussed below.

6.1 *REP has a significant improvement in the C2 Rationality, C4 Concreteness, C Generate precise ideas and D2 improve ideas of students' creative thinking*

Quantitative data analysis underscores distinctive enhancements in Creative Thinking across several dimensions. Specifically, significant disparities emerged in B1 Novelty, B2 Value, C Generate Precise Ideas, C1 Accuracy, C2 Rationality, C3 Logicality, C4 Concreteness, and D2 Improve Ideas. These results affirm the efficacy of the proposed teaching mode in augmenting students' Creative Thinking within the aforementioned realms. Elaborating on these findings, students demonstrated adeptness in generating innovative notions concerning cultural artifact functions, synthesizing ideas infused with both market and cultural value. Within this framework, design thinking, coupled with tenon culture and programming technology, facilitated the embodiment of accuracy, rationality, logic, and concreteness, thereby refining idea precision. The study additionally offers suggestions for model iteration and refinement (Piaw, 2014).

However, no significant distinctions were observed in A Generate Diverse Ideas, A1 Fluency, A2 Flexibility, A3 Comprehensiveness, B Generate Creative Ideas, B3 Feasibility, D Evaluate and Improve Ideas, and D1 Evaluate Ideas. Comparing the outcomes with the pilot study, congruence in significance levels is noted between the formal study and the pilot study. Notably, B1 Novelty and C2 Rationality, which exhibited no significant difference in the pilot study, displayed substantial variance in the formal study. This shift may be attributed to user attribute analyses of the design thinking divergence tool, influencing participants' engagement with multifaceted thinking angles. Moreover, the application of the six thinking caps method fostered heightened rationality considerations during scheme design (Liedtka, 2015).

Comparing outcomes between the FPP group and the REP group, the REP group exhibited pronounced advancements in C2 Rationality, C4 Concreteness, C Generate Precise Ideas, and D2 Improve Ideas, while the FPP group exhibited minimal progress. This divergence suggests that the guided teaching model proposed herein offers distinct advantages in bolstering students' rationality, precision in generating ideas, and refining concepts. Students exhibited tendencies to formulate reasoned and specific inquiries, refine concepts, and engage in critical self-evaluation, facilitating iterative work development (Ishiguro et al., 2022). Substantial enhancements in B2 Value, C1 Accuracy, and C3 Logicality were evident in both the FPP and REP groups, signifying deep-seated exploration of work values, meticulous accuracy, and rigorous theoretical application in their creative endeavors (Rochmad et al., 2018).

However, limited improvement was witnessed in A Generate Diverse Ideas, B3 Feasibility, and D1 Evaluate Ideas. These outcomes underscore the need to bolster students' flexible strategy in diversifying idea generation and guide students toward profound iterative thinking rooted in real-world challenges (Erzurumlu & Erzurumlu, 2015). Therefore, we suggest that educators pay special attention to the diversity of student-generated ideas, the feasibility of student solutions, and the in-depth evaluation of student-generated ideas in teaching. Of course, more implicit dimensions of creative thinking can be explored for in-depth assessment, such as observing the psychological characteristics of students in the process of D1 Evaluate Ideas, their subjective degree of self-evaluation of works may be too high, leading them to give up D1 Evaluate Ideas.

6.2 *REP has a significant improvement in cultural understanding and cultural identity of students' cultural competence, but no significant improvement in cultural practice*

Concerning Cultural Competence, noteworthy trends emerged in the REP group's performance. Notably, substantial disparities were evident in the overall pre-test and post-test, as well as in Cultural Understanding and Cultural Identity, while no significant differences manifested in Cultural Practice. These outcomes mirrored the pilot study's findings, underscoring that students demonstrated a robust grasp of mortise and tenon culture's essence and significance, yet encountered challenges in effectively translating this cultural connotation comprehension into tangible behaviors. Prior investigations have demonstrated that integrating local cultural content into STEAM projects can invigorate students' engagement with their immediate community and society (Kim & Chae, 2016; Kim, 2016). However, research thus far has not conclusively demonstrated students' successful internalization of cultural knowledge into actionable social practices. Although REP group and FPP group both show significant differences in the cultivation of Cultural Competence, the numerical dispersion degree of REP group is smaller and more concentrated and stable, indicating that REP is more effective in cultivating students' Cultural Competence.

6.3 *Under REP, students' creative thinking has an impact on cultural competence*

In examining the interplay between Creative Thinking and Cultural Competence, the study identifies that students' Creative Thinking indeed influences their Cultural Competence. However, it's noteworthy that Creative Thinking doesn't appear to directly impact Cultural Identity. Specifically, the dimensions of Creative Thinking encompassed by A Generate Diverse Ideas, B Generate Creative Ideas, C Generate Precise Ideas, and D Evaluate and Improve Ideas demonstrate an influence on Cultural Competence. This influence is particularly pronounced in relation to Cultural Understanding and Cultural Practice. Meanwhile, only A Generate Diverse Ideas and D Evaluate and Improve Ideas exhibit an influence on Cultural Identity. This aligns with the findings of Gao Ruixiang et al. (2022), who concluded that cultural learning methodologies play a pivotal role in nurturing students' creativity and that virtue education fosters favorable traits for knowledge assimilation. Thus, in higher education, virtue education contributes to the establishment of traditional Chinese virtues such as diligence, responsibility, and ambition, while upholding the Confucian learning culture (Gao et al., 2022). These findings correlate with the current research's conclusions regarding the link between Creative Thinking and Cultural Competence. Integrating cultural learning into education not only enhances students' Cultural Competence but also supports the development of Creative Thinking. Consequently, future C-STEAM education should emphasize the nurturing of students' Cultural Understanding and Cultural Identity, enabling the internalization of cultural knowledge into actionable behavior. This approach would stimulate the realization of Cultural Practice's effects and provide holistic support for both Cultural Competence and Creative Thinking cultivation.

6.4 *REP can significantly improve students' engineering thinking*

Regarding Engineering Thinking, there is a significant overall difference between the pre-test and post-test scores of students in the REP group, consistent with the pilot study's outcome. This finding implies that the teaching approach introduced in this study equips students with a grasp of Engineering Thinking within the broader engineering process. Prior research underscores that Reverse Engineering Teaching can facilitate students' comprehension of the correlation between vehicle power and speed in robotics courses. This exposure allows students to develop an early grasp of mechanical concepts and Engineering Thinking (Chambers et al., 2008).

Scholars have contended that critical thinking assumes a pivotal role in shaping Engineering Thinking, as engineers rely on continuous reasoning during the design and implementation phases (Kenyon & Beaulac, 2014). Moreover, some researchers advocate for the integration of Engineering Thinking with the profession, enabling students to acquire both professional competence and the distinctive thinking patterns and attributes associated with the entire engineering domain. This approach establishes a foundation for students to evolve into high-quality engineers endowed with genuine innovative capabilities (Shang et al., 2013). Therefore, we suggest that teachers can guide students to reason about engineering steps in class to promote their Engineering Thinking.

7. Conclusion and future study

7.1 *Reverse engineering pedagogy in C-STEAM teaching mode and its strategy selection*

In this study, the primary framework for teaching is anchored in the 6C model of C-STEAM. It amalgamates the instructional stages of the Deconstruction Recovery Model, Troubleshooting Model, Element Minitrim Model, and Structural Innovation Model from Reverse Engineering Pedagogy. The process of forming thinking is divided into four dimensions: product, process, result, and thinking, with two fundamental formats of thinking: divergence and convergence. This configuration shapes a T-Shape thinking process that propels both divergent and convergent thinking across the four dimensions. Consequently, the C-STEAM Reverse Engineering Teaching Mode is established, encompassing six components: (1) Cultural products trial and situational perception; (2) Decomposition and restoration of cultural artifacts; (3) Understanding of cultural connotation and exploration of characteristics; (4) Reconstruction and creation of cultural products; (5) Connection with social promotion; (6) Summation, evaluation, and reflection.

This comprehensive teaching approach further delineates the specific application of teaching strategies, such as situational experience teaching strategy, heuristic teaching strategy, scaffolding teaching strategy, cooperative teaching strategy, inquiry teaching strategy, problem-solving teaching strategy, technology realization teaching strategy, innovation and creation teaching strategy, and multiple evaluation feedback strategy. Consequently, this construction encapsulates four complete T-Shape thinking processes, each permeating the entirety of the teaching procedure with its expansive and profound thinking scope. Therefore, in educational settings, the REP mentioned above can be utilized. By decomposing and micro-innovating existing works, students can grasp the aggregation and divergence of thinking, thereby promoting the cultivation of their innovative thinking.

7.2 *The effectiveness of reverse engineering pedagogy in C-STEAM*

The C-STEAM Reverse Engineering Teaching Mode and its associated strategies were implemented in quasi-experimental research, conducted separately in pre-experimental and formal experiment stages. Various statistical analysis techniques, including independent sample T-test, paired sample T-test, correlation analysis, and regression analysis, were employed to scrutinize questionnaire data, bidirectional scale responses, and learning achievement test papers. These analyses aimed to substantiate the efficacy of the devised C-STEAM Reverse Engineering Teaching Mode and Strategy.

The findings demonstrate notable enhancements within the experimental group as compared to the control group, particularly in aspects of Creative Thinking such as Rationality, Concreteness, Generation of Precise Ideas, and the Improvement of Ideas. Additionally, both the experimental and control groups exhibited significant improvements in elements like Value, Accuracy, and Logicality of Creative Thinking, the overarching Cultural Competence, Cultural Understanding, Cultural Identity and Engineering Thinking. However, with regard to the generation of Diverse Ideas, Flexibility, and the Evaluation of Ideas within Creative Thinking, as well as Cultural Practice within Cultural Competence, neither the experimental nor control groups showed substantial advancement. Overall, the study underscores the merits of the C-STEAM Reverse Engineering Teaching Mode, notably in relation to students' Creative Thinking, Cultural Competence and Engineering Thinking. It demonstrates the suitability and feasibility of the REP in C-STEAM education, expanding the methods for cultivating creative thinking within STEAM education. Additionally, it addresses the deficiency in higher education C-STEAM programs regarding the cultivation of students' creative ability and cultural competence.

7.3 *Future study*

7.3.1 *Combined with the psychological implicit psychology in-depth analysis of the internal reasons*

The Creative Thinking data analyzed in this study predominantly encompass explicit behaviors and selfquantification provided by students. However, the implicit dimensions of students' Creative Thinking have not been fully explored or validated as well as lacking a huge sample size. To augment the comprehensiveness of the research, future investigations should amalgamate insights from the internal psychological mechanisms, unearthing the concealed aspects of students' Creative Thinking (Redifer et al., 2019). For a more thorough understanding of students' creative thinking, methods like in-depth interviews and psychometric tools can be employed. These approaches help uncover the underlying psychological mechanisms of creative thinking, such as curiosity and reasoning. By exploring the relationship between these factors and creative thinking performance, a more comprehensive picture of students' creative abilities can be obtained. By delving into this implicit information, a deeper understanding of the underlying causes of observed phenomena can be garnered. An approach of this nature would allow for a holistic analysis that combines both explicit behaviors and implicit information, shedding light on the various factors and fundamental principles governing students' Creative Thinking. Such an integrated exploration would contribute to the refinement and broadened applicability of the evaluation index system and teaching mode, ultimately facilitating wider dissemination and adoption.

7.3.2 *To dig deeply the creative thinking path of students and provide direct evidence for teaching feedback and intervention*

The T-Shape Creative Thinking process established in this study, while a significant step forward, remains relatively straightforward. To further enhance its robustness, two critical avenues necessitate exploration. Firstly, a broader spectrum of data collection methods and analysis techniques is imperative to comprehensively unveil the trajectories of students' Creative Thinking paths. This endeavor will serve to affirm the accuracy and efficacy of these delineated thinking paths. Moreover, a more intricate investigation is needed to refine the underlying dynamics of divergent and convergent thinking. This involves delving deeper into intuitive and logical thinking patterns, culminating in the formulation of comprehensive thinking models and mechanisms. The purpose of such an endeavor is to furnish direct evidential substantiation, thereby bolstering the value of teaching feedback and interventions.

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Conflict of interest

The authors declare no competing financial interest.

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