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Empathy Design Thinking: cultivating creative minds in primary education

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This research explores the application of an Empathy Design Thinking (EDT) curriculum within primary education, guided by the principles of Experience, Empathy, Exploration, and Evaluation, to examine its effect on fostering student creativity in a Chinese context. The curriculum was redesigned into a streamlined, modular format for ease of integration into existing educational frameworks. Findings demonstrate a positive impact on students' creative thinking abilities, particularly in enhancing fluency and flexibility, with notable mentions of empathy's vital role in the educational process. This study aligns with global educational trends emphasizing the need for empathetic and comprehensive learning experiences, offering insights into the potential of EDT to enrich creative education for primary students, educators, curriculum developers, and policymakers.

KEYWORDS

Empathy Design Thinking, creative education, curriculum development, primary education, Chinese context

1 Introduction

In response to the 21st century's evolving educational needs, there is a worldwide shift toward prioritizing creative skills, supported by educational reforms and aligned with the United Nations' Sustainable Development Goal 4: Quality Education (Facer and Sandford, 2010; Cobo, 2013; Boeren, 2019; Tight, 2021). This trend emphasizes the importance of fostering creativity in primary students, a task that is becoming increasingly vital within China's rapidly changing educational landscape. The move toward innovative teaching methods in China aims to enhance students' creative thinking and collaboration, preparing them for the complexities of a globalized world (Jia et al., 2017; Mansilla and Wilson, 2020; Hsia et al., 2021; Liu et al., 2021; Gray and Exter, 2023; Guaman-Quintanilla et al., 2023). Our study is designed to design a curriculum that reflects these modern teaching approaches, with a focus on boosting creativity among Chinese students.

This paper examines the role of creativity in primary education through Empathy Design Thinking (EDT). EDT, focusing on understanding and addressing the needs and experiences of others, creates a deeper engagement with real-world situations. This approach enables students to connect more fully with their learning, moving beyond traditional exam-centered education. Through integrating empathy, students develop a

comprehensive understanding of their study subjects, and with design thinking (Cross, 2007, 2023; Pande and Bharathi, 2020), they are trained to tackle challenges in a creative way. Our study outlines the research methodology and presents insights from case studies that demonstrate the curriculum's practical impact. By adapting to innovative educational strategies in China, this research contributes to the ongoing conversation about updating educational systems to meet the needs of a continually changing global environment. Our goal is to enhance student creativity, equipping them for success in a swiftly transforming world.

2 Related works

2.1 Creativity and EDT in education

The understanding of creativity in educational theory has significantly shifted from a narrow emphasis on intelligence to a broader appreciation of various cognitive abilities. This change, strongly advocated by early scholars like Guilford (1967), challenged the prevailing IQ-centric notion of creativity. Guilford highlighted the need to recognize a multitude of creative abilities in children, which marked a departure from traditional educational focuses and embraced a more inclusive view on nurturing creative skills from a young age. Further advancements in this field were made by the contributions of Piaget (So, 1964) and Vygotsky (Hausfather, 1996), who illustrated the significant role that social and environmental contexts play in the development of children's creativity. Contrary to the idea of creativity as an innate quality, they proposed that it evolves through interaction and conducive learning environments, suggesting that creativity can be cultivated and enhanced through educational practices. By the end of the 20th century, the introduction of Amabile's (1983) componential theory and Gardner's (2011) theory of multiple intelligences underscored the necessity for education systems to support creative thinking across various domains beyond just the arts. These theories emphasized creativity as arising from the combination of personal abilities, motivation, and the external environment, advocating for an educational approach that fosters creative problem-solving skills. In recent times, the integration of digital technologies in education has further highlighted the importance of creativity in preparing students for the future, offering new opportunities for creative expression and collaborative work (Klapwijk and van Doorn, 2015; Niu et al., 2022). Within these developments, EDT, alternatively known as "design thinking in education" or "empathetic creative learning," is introduced as an innovative educational strategy (Montero, 2023; Liu et al., 2024; Xiang et al., 2024). This approach aligns with evolving views on creativity, demonstrating the adaptability and broad applicability of EDT principles across various educational contexts. EDT emphasizes empathy in the learning process, aiming to deepen students' engagement with real-world challenges. This approach not only resonates with the latest shifts in educational reform but also seeks to address existing gaps in promoting creativity among primary students, offering a fresh perspective on preparing students with the critical thinking and adaptive skills necessary for tomorrow's challenges.

2.2 Empirical evidence on EDT's impact in educational settings

Empirical evidence underscores the profound impact of EDT on enhancing creativity in educational settings, particularly through the incorporation of experiential learning. This method is crucial in fostering both empathy and creativity among primary students. Championed by Resnick's (2017), the integration of exploratory, kindergarten-style learning offers a persuasive framework for educational methodologies. The Scratch programming language, developed by Resnick et al. (2009) and Resnick and Rusk (2020), exemplifies how digital tools can support a learning environment that stimulates creative thinking. These platforms enable students to engage in experiential learning experiences that are both engaging and educational. The investigations of Saggar et al. (2017, 2021) into the neuroscientific underpinnings of learning environments underscore the profound impact such environments can have on activating brain regions associated with creativity, offering robust scientific support for the methodologies employed within the EDT framework. This research emphasizes the significance of engaging and empathetic learning experiences in stimulating creative thought processes, highlighting its effectiveness in fostering an educational environment that fosters creativity. The work by Martin and Murphy (2022) on the adaptability of EDT practices, particularly through digital platforms, showcases the flexibility and wide applicability in enhancing creative development across diverse learning settings. These studies collectively validate its integral role, underlining how it serves as a foundational strategy in nurturing creativity and empathy among students. The incorporation of EDT into the educational landscape represents a significant alignment with modern pedagogical strategies, contributing substantially to the holistic development of students' creative capacities (Goldman et al., 2009; Marsden and Wittwer, 2022). This evidence strongly supports the adoption of EDT as a critical component of contemporary education, designed to prepare students for a future where creative problem-solving and empathetic understanding are essential.

2.3 Empathy as a core element of design thinking in education

EDT in education places empathy at the heart of the design thinking process, marking a shift from conventional problem-solving to a methodology deeply rooted in understanding human emotions and experiences (Rittel and Webber, 1973; Simon, 1973). This evolved approach adopts a cyclical process of empathizing, defining, ideating, prototyping, testing, implementing, and reflecting, emphasizing the designer's deep empathy with users as a cornerstone for innovation (Schön, 1992; Akin and Akin, 1996; Maher and Poon, 1996; Dorst and Cross, 2001; Norman, 2023). Further, Kannengiesser and Gero (2019) illustrate how combining fast, intuitive decision-making with thoughtful analysis can refine the design thinking process, particularly in education (Matthews and Wrigley, 2017; Gero and Milovanovic, 2020). Here, empathy transcends mere understanding, pushing students

to tackle challenges with both intellect and emotional insight (Dym et al., 2005; Leifer and Steinert, 2011; Lewrick et al., 2018). EDT emphasizes cultivating adaptability and creative thinking, preparing students to navigate and innovate within the complexities of the modern world (Armstrong, 2016; Lee and Park, 2021; Kermavnar and Desmet, 2024).

By integrating empathy at every stage, EDT fosters a learning environment where students are prepared to think creatively and develop solutions that are mindful of human needs and experiences (Kouprie and Visser, 2009; Levy and Hadar, 2024). This approach extends past conventional teaching, fostering a sense of responsibility and understanding toward others. It establishes a foundation for students to develop into empathetic innovators and thoughtful leaders in their future endeavors. Through this lens, EDT emerges as a critical educational tool, preparing students to meet the challenges of an interconnected and rapidly changing global landscape with empathy, creativity, and resilience.

2.4 Integrating EDT into primary education in China

The introduction of China's "Innovation and Entrepreneurship" and "Double Reduction" policies represents a critical shift in the educational paradigm, laying the groundwork for the seamless integration of EDT into the core of creative education. Outlined on authoritative government platforms (gov.cn/zhengce/shuangchuangzck and moe.gov.cn/jyb_xwfb/gzdt_gzdt/s5987/202202/t20220225_602315, accessed on 1 April 2024), these reforms indicate a strategic shift toward redefining the educational structure to equally value the development of innovative abilities and creative reasoning, in conjunction with scholastic accomplishments. By moving away from the conventional focus on memorization and test performance, these policies align with the fundamental principles of EDT. They advocate for a learning environment enriched with critical thinking, creative pursuit, and empathy—essential elements for comprehensive learning (Phan et al., 2010; Reshetnikova, 2018). In particular, the "Double Reduction" policy, by reducing the pressures of too much homework and additional tutoring, opens up new possibilities for students to engage in creative activities centered around EDT (Xue and Li, 2023; Li et al., 2024). Although these reforms pose certain challenges, such as the disruption of established tutoring practices and the diverse approaches adopted by parents to adapt to these changes (Wang et al., 2022; Qian et al., 2023; Teng et al., 2024), they fundamentally affirm a dedication to cultivating an educational environment that prioritizes creativity and innovation. This paradigmatic shift not only harmonizes with but also actively promotes the incorporation of EDT principles, signaling a transformative era for primary education in China.

2.5 Bridging the gaps with EDT

The synthesis of previous sections highlights the evolving nature of creativity in education, the significance of experiential learning, and the impactful role of China's educational policies. These discussions point to critical research gaps, especially in applying empathy within educational contexts (Han et al., 2021; Stephan, 2023; Pivonka et al., 2024). The transition from theoretical explorations of creativity to their application in today's classrooms, guided by these policies, suggests a move toward more dynamic and empathetic educational models (Heylighen and Dong, 2019; Dotson et al., 2020; Bush et al., 2024; van Rheden et al., 2024). However, there remains a distinct need for research that connects these foundational theories with the realities of contemporary Chinese education, underscoring the importance of empirical studies that bridge this divide.

While experiential learning is recognized for its positive impact on creativity, there is a gap in seamlessly integrating such approaches into China's formal education system. The development and application of culturally relevant learning strategies that fit within China's educational norms are urgently needed (Kangas, 2010). Initial evaluations of policy impacts are promising, yet comprehensive, longitudinal research is essential to fully grasp these policies' effects on students' creative development, academic achievements, and wellbeing. Emphasizing empathy in design thinking emerges as vital for education. Given primary students' limited exposure to "Innovation and Entrepreneurship" practices, an empathetic approach that connects them with broader global challenges is necessary (Niemi and Liu, 2021; He et al., 2023). EDT, with its core focus on understanding others, moves beyond conventional learning objectives to encourage a profound engagement with the world, fostering creative solutions.

Therefore, this study promotes the implementation of EDT, as conceptualized by the authors, to address the identified gaps in research and practice. In the context of primary education, we specifically aim to prioritize fostering empathy as a form of innovation, distinguishing our approach from the entrepreneurship focus typically more suited to college students. Incorporating EDT into teaching methods and teacher training programs is expected to greatly enhance students' creativity, preparing them for future challenges. Promoting EDT as an integral component of the ongoing evolution of creative education in China is designed to harmonize with recent policy shifts toward more dynamic, learner-focused pedagogical models. This approach not only meets the educational goals of fostering creativity and innovation but also helps students develop a well-rounded understanding of global challenges. It encourages them to solve real-world problems with empathy and creative solutions.

3 Curriculum development and foundations

3.1 Curriculum framework at Beijing Normal University experimental primary school

The curriculum framework at the Primary School, anchored in EDT, demonstrates the application of innovative educational strategies in primary education. Reflecting the knowledge discussed above, this curriculum has evolved over the years since its initial launch in 2017, with continuous refinement based on classroom

experiences and feedback. Each iteration of the EDT course was conducted over a semester, comprising one class per week for 2 h across 10 weeks. This structure facilitated an immersive and comprehensive learning experience for the students, encompassing a 4E principles of Empathy, Enthusiasm, Enlightenment, and Exploration. This approach contrasts with Resnick's (2017) 4P Principles of Projects, Passion, Peers, and Play, offering a more psychology-driven methodology tailored to the developmental needs of primary students.

The course engages students through a discovering-analyzing-solving process divided into three stages: theme exploration, design expression, and prototype production. This structure ensures a balanced emphasis on empathy development, collaborative working, and practical application of design thinking principles. The course schedule includes: Week 1: Innovation Introduction. Week 2: Empathy Cultivation. Week 3: Cause Insight. Week 4: Thought Expansion. Week 5: Collaborative Innovation. Week 6: Solution Refinement. Week 7: Prototype Design. Week 8: Production Practice. Week 9: Program Refinement. Week 10: Results Report and Course Summary.

Each course hosted 30 students, representing 20% of the grade, randomly selected from different classes to ensure diversity and inclusiveness in team formation. The students were grouped into teams of three, forming a total of 10 teams per course. This team arrangement was designed to foster collaborative learning and encourage peer interactions, reinforcing the curriculum's focus on empathy and creativity. The course team, comprising mentors and assistants of undergraduate and graduate students in our institute from transdisciplinary backgrounds, facilitated the curriculum delivery, ensuring that it resonated with the students' cognitive and emotional development stages. Their backgrounds contributed to a rich, multi-faceted educational experience for the students.

This EDT curriculum is a testament to the efficacy of innovative educational practices in nurturing creativity. Its evolution over the years, driven by hands-on classroom experiences and continuous improvements, showcases a dynamic model of education that prepares students to meet future challenges with creativity, empathy, and collaboration.

3.2 Adaptation for broader application

The process of adapting the EDT curriculum for broader educational contexts has been enriched by contributions from several global experts in the field. These specialists were invited to observe the course over the years, offering valuable suggestions and insights that have significantly influenced the curriculum's evolution and adaptability. Professor Donald Norman emphasized the importance of user experience in education, stating, "a deep understanding of the user's experience is essential in creating solutions that resonate on an emotional and practical level." This insight has been instrumental in reinforcing the curriculum's focus on empathetic and experience-based learning. Similarly, Professor Mitchell Resnick's guidance focused on enhancing exploration and evaluation within the learning process. His advice, "encouraging students to explore and evaluate their own learning journeys fosters a deeper connection with the subject matter and a greater capacity for creative thinking," has been crucial in shaping the curriculum's approach toward fostering independent and reflective thinking in students.

In response to feedback about the original 4E principles being somewhat vague regarding design thinking actions, the curriculum was enhanced to focus on Experience, Empathy, Exploration, and Evaluation (see Figure 1). This new framework provides a clearer and more actionable set of principles for educators and students alike.

In light of the challenges of integrating the comprehensive EDT curriculum into the existing primary education setup and considering the demands of regular academic learning and exams, as well as the "Innovation and Entrepreneurship" and "Double Reduction" policies, the curriculum underwent significant restructuring. The curriculum was restructured into a more concise, modular-based design, spanning 4 half-days, each comprising a 3-h class session, as recommended by primary school teachers. This adaptation ensures the course's feasibility within typical primary education timetables.

Furthermore, the application of specific contexts and themes within the course has proven to be more effective in fostering creativity. By contextualizing learning experiences, students are more engaged and able to apply their creative skills in meaningful ways.

The experiences and insights gained from this transdisciplinary collaboration have also informed the teaching approaches at the college level. The skills of engaging and empathizing with learners, developed through the primary school application of the curriculum, are seen as valuable in higher education settings, highlighting the universal relevance of these teaching principles.

4 Case studies

4.1 The pilot study

The pilot study focused on refining the curriculum into a practical and reusable 4 half-day format, aiming to integrate it effectively into the regular academic schedule of primary education.

4.1.1 Study participants and structure

Thirty students aged 9 to 13 were enrolled in the pilot study, distributed into six teams to encourage collaboration, a core element of the EDT curriculum. This team-based approach is designed to reflect the collaborative nature of modern educational and professional environments, enhancing the curriculum's real-world applicability. Diversity within teams was emphasized to incorporate various skill levels and perspectives, vital for fostering a rich, creative process. Teams engaged in the design thinking process from conception to execution, offering students a holistic and practical learning experience. The study's structured yet flexible environment aimed to empower students, promoting autonomy in their creative journey while equipping them with essential design thinking tools and methods. These arrangements provided insights into EDT's effectiveness and informed considerations for its broader implementation, underscoring the significance of collaborative, hands-on learning in developing key student competencies.

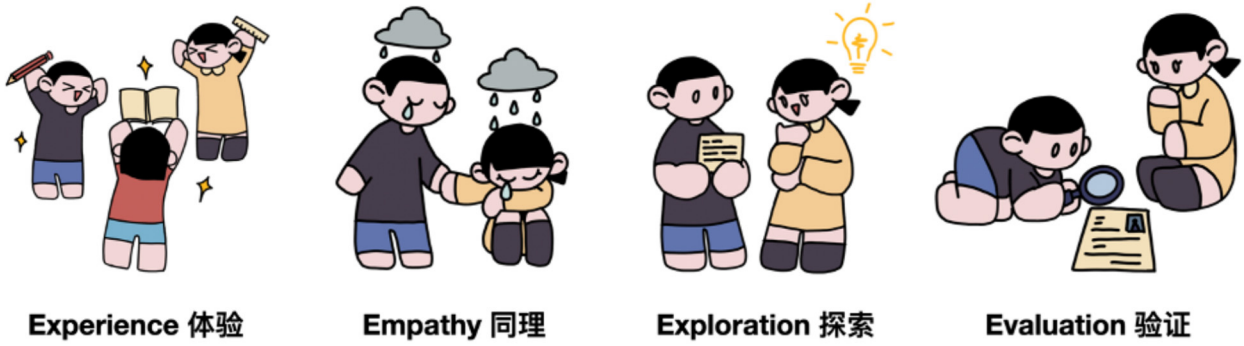

FIGURE 1
The 4E principles: Experience, Empathy, Exploration, and Evaluation.

4.1.2 Theme and topics

The pilot study's theme, "space exploration," aligned with China's space ambitions, encompassed three main topics: space stations, space shuttles, and astronauts. This thematic choice engaged students with contemporary and future space technologies, offering real-world relevance to their learning. Teams, each assigned one topic, followed the design thinking process from empathizing with space-related challenges to defining and solving specific problems. The process involved brainstorming innovative solutions, creating prototypes, peer testing, and presenting final solutions in class. This approach allowed students to transform their ideas into tangible prototypes and gain feedback, enhancing their understanding of practical issues in space exploration. Through this thematic framework, the study effectively bridged classroom learning with real-world scientific advancements, fostering creativity, and an appreciation for the complexities of space science.

4.1.3 Methodology and data collection

Qualitative methods assessed curriculum effectiveness and student experiences. Observations and interviews by the teaching team were key. Classroom observations captured student engagement and teamwork processes. These insights were crucial for evaluating how students applied design thinking in practice. Post-course interviews allowed students to reflect on their experiences and learning outcomes, providing valuable insights into their engagement with the curriculum. We also kept reflective journals, offering additional perspectives on curriculum delivery and effectiveness. This qualitative approach provided a comprehensive view of the curriculum's impact, essential for assessing its role in enhancing creativity and collaboration in primary education.

4.1.4 Results and outcomes

The successful adaptation of the EDT curriculum into a structured 4 half-day intervention is a testament to its flexibility, depth, and educational impact. Far from being limited to a mere hour of exposure on the 1st day, the essence of EDT—encompassing the core principles of Experience, Empathy, Exploration, and Evaluation—was interwoven throughout all activities and sessions, ensuring a rich, continuous engagement with these foundational concepts. This structure facilitated not only seamless integration with existing school schedules but also ensured that the integrity and depth of the educational experience were maintained. The effectiveness of this adapted format was vividly demonstrated through the enthusiastic participation of students, their evident development of creative skills, and the enhancement of their collaborative abilities. These outcomes affirm the curriculum's capacity to meet its educational aims within a condensed timeframe, showcasing its practical applicability and significant relevance in the primary education context. The broad potential of the EDT approach for diverse educational settings became evident, highlighting its ability to cultivate essential 21st-century competencies such as creativity, critical thinking, and collaboration among students.

Reflecting on the study's outcomes, the implementation of the 4E principles was not a one-off occurrence but a continuous thread that ran through the entire program. The initial focus on Experience and Empathy laid the groundwork for a deeper understanding and engagement with the subjects at hand, enabling students to connect empathetically with their projects. As the course progressed, Exploration and Evaluation took center stage, with students employing innovative strategies and refining their projects through constructive peer feedback. This iterative, feedback-driven process is a defining characteristic of the EDT methodology, emphasizing the dynamic interplay between learning and application.

The qualitative feedback collected from participants further validates the comprehensive embedding of EDT principles throughout the program. One student remarked, "Working on my project helped me understand how to turn ideas into real solutions," highlighting the curriculum's successful emphasis on real-world application. Another student reflected, "I learned how to listen and work with others, which was challenging but fun," underscoring the curriculum's dedication to fostering empathetic collaboration and interpersonal skills. The pilot study not only confirmed the feasibility and effectiveness of implementing the EDT curriculum in a condensed format but also illuminated the profound influence of

the 4E principles in crafting a holistic and meaningful educational experience (see Table 1). This journey reinforces the feasibility of integrating EDT across various educational paradigms, heralding a future in which key 21st-century skills are cultivated through empathetic, creative, and collaborative learning experiences.

4.2 The main study

Building on the pilot study, this study aimed to validate the 4 half-day EDT curriculum's effectiveness in a real-world primary school context. This was in line with the research objective of integrating EDT effectively into primary education. The study provided insights into how the adapted curriculum impacts student creative skills, crucial for confirming its practicality and scalability in a typical educational setting.

4.2.1 Study participants and structure

In our study, we focused on a cohort of 60 fifth-grade students, aged 10–12, evenly divided by gender, to explore creativity during a pivotal developmental stage (Siew and Ambo, 2020; Zhang et al., 2023). This specific age range was chosen to provide a detailed and comparative analysis of creativity development. The experimental group consisted of 30 students, of which 28 (comprising 12 males and 16 females) successfully completed the curriculum within six teams. Similarly, the control group included 30 students, serving as a comparative benchmark to evaluate the curriculum's impact. These participants were randomly selected from various classes within the same grade, making up 38% of the total grade population, to promote diversity and ensure a broad representation in our study. This random selection process added an element of impartiality to the study and allowed for a broad representation of student abilities and perspectives. The study's structure, incorporating pre- and post-tests, along with comprehensive surveys from students and parents, provided a holistic understanding of the curriculum's impact on fostering creativity and collaborative skills in a primary educational setting.

4.2.2 Theme and topics

The theme of "space exploration" was retained from the pilot study, maintaining its alignment with China's strategic interests in space science and technology. However, an enhanced approach was adopted to deepen the learning experience. Alongside the existing topics of space stations, space shuttles, and astronauts, the study introduced foundational knowledge about space exploration to provide students with a more comprehensive understanding of the subject. This introduction included essential concepts and recent advancements in space technology, aiming to inspire and inform students as they embarked on their design thinking journey. An addition to this study was the use of scaled models related to the topics of space stations, shuttles, and astronauts. These models provided concrete examples for the students, improving their capacity to understand and relate to the complexities and challenges involved in exploring space. The hands-on experience with these models allowed students to interact more closely with the subject matter, fostering a deeper connection and understanding.

By incorporating educational content and scaled models into the curriculum, the main study provided a richer, more immersive learning environment. This approach ensured that the students were not only applying EDT skills but also gaining valuable knowledge about space exploration, thereby bridging the gap between theory and practice. The thematic consistency with the pilot study, coupled with these enhancements, reinforced the curriculum's relevance and effectiveness in fostering creativity and innovation in primary education.

4.2.3 Methodology and data collection

The methodology and data collection for the main study were carefully designed to assess the curriculum's effectiveness in enhancing student creativity. Utilizing the curriculum outlined in Table 1, the study incorporated the refined 4E principles to guide instructional activities.

Same qualitative methods in the pilot study were applied. In addition, to quantitatively evaluate the influence of EDT-based learning on the students' creativity, this study employed several standardized assessments, including the Williams Prefer Measurement Forms (WPMF) (Claxton et al., 2005), the Torrance Tests of Creative Thinking (TTCT) (Kim, 2006), and the Toronto Empathy Questionnaire (TEQ) (Spreng et al., 2009). These tools were chosen to comprehensively measure aspects of creativity, creative thinking capabilities, and empathy among participants.

- WPMF excels in measuring divergent thinking and a predilection for complexity, which are indicative of a student's potential for creativity (Plucker et al., 2004). This tool assesses an individual's attraction to innovation and diverse experiences, critical elements of creative involvement. Due to its proven reliability and validity in pinpointing preferences associated with creativity, WPMF is considered ideally suited for capturing the diverse aspects of creativity that the EDT curriculum aims to develop.
- TTCT is renowned as the gold standard for assessing creative thinking, evaluating divergent thinking through four key dimensions: fluency, flexibility, originality, and elaboration (Almeida et al., 2008). Together, these dimensions offer a comprehensive perspective on a student's creative thinking ability, from the generation of ideas (i.e., fluency) to the capacity for innovative thought (i.e., originality). TTCT's extensive evaluative power, reinforced by its ability to predict creative accomplishments, is vital for determining the impact of the EDT curriculum on students' creative thinking prowess.
- TEQ is specifically designed to measure empathy by detailing both emotional and cognitive reactions to the experiences of others (Voultsos et al., 2022). As a fundamental aspect of the EDT, empathy enhances deeper engagement with learning material and promotes a collaborative learning atmosphere. With its strong reliability and validity, TEQ is instrumental in precisely evaluating the progression of empathetic understanding facilitated by the curriculum.

TABLE 1 Schedule of the four half-day format of the EDT course.

Class	Principles	Hour 1: activities	Materials	Hour 2: activities	Materials	Hour 3: activities	Materials
1	Experience, empathy	Opening ceremony	Team T-shirts	Empathy cultivation	Report slides	Collage making	Tinkering materials, sticky notes, papers, glue sticks
		Team formation	An ice-breaking embodied game	Design thinking introduction		Focus groups	People, object, environment, message, service (POEMS) toolkit
2	Empathy, exploration	Affinity diagrams	Large paper, Sticky notes	Jobs-to-be-Done (JTBD)	Sticky notes	Flower mind-maps	Large paper, color pens
						C-Boxes	C-Boxes toolkit
3	Exploration, evaluation	Interaction design	Report slides	Prototyping	Tinkering materials	Peer testing, iterative refinement	User experience questionnaire (UEQ) scale
		User interface design briefing				Presentation preparation	Report template
4	Evaluation, experience	Presentation prep	Report template	Final presentations		Award ceremony, discussion, reflection	Certificates, satisfaction survey

At the study's onset, baseline data and background information were collected from both the experimental and control groups through these questionnaires. The experimental group then participated in the structured curriculum over 2 weeks, with four classes in total, meeting twice weekly. Meanwhile, the control group adhered to their standard school curriculum during the same period. Upon completing the final class, both groups were re-assessed with the same questionnaires to evaluate the intervention's impact on their learning outcomes, behaviors, and other developmental areas.

The collected data from pre- and post-assessments were subjected to statistical analysis to pinpoint any significant discrepancies between the experimental and control groups, a crucial step in assessing the intervention's efficacy. Complementing this, similar qualitative methods to those used in the pilot study, including observations, post-course interviews, and reflective journals maintained by the teaching team, offered a comprehensive array of insights. These qualitative data played a crucial role in uncovering the subtleties of student engagement, teamwork dynamics, and overall interaction with the curriculum, providing invaluable insights into the educational impact of the intervention.

In line with ethical research practices, participation was strictly voluntary, accompanied by rigorous confidentiality protocols to protect participants' privacy and personal data. The research was carefully limited to gathering only information pertinent to the study, with all data being processed and stored anonymously to ensure scientific integrity and reliability.

4.2.4 Results and outcomes

4.2.4.1 Creativity tendency test results

This study conducted a detailed analysis of the creativity tendency scores for both the experimental and control groups, utilizing statistical tools like Excel and SPSS 27. The results derived from these analyses offer insightful perspectives on the impact of the EDT curriculum.

Contrary to initial appearances, the data reveals a complex story of the EDT curriculum's impact. While the numerical decrease from pre-test to post-test scores in the experimental group might suggest a decline in creativity tendency, a deeper analysis offers a different perspective. The statistical significance of this change prompts a reevaluation of the metrics used to assess creativity and underscores the multifaceted nature of creative development. In comparison, the control group's scores remained stable, with no significant change, highlighting the distinct influence of the EDT intervention on the experimental group. This stability contrasts sharply with the experimental group's experience, suggesting that traditional measures may not fully capture the growth in creativity engendered by the EDT curriculum.

Initial comparisons between the experimental and control groups showed no significant differences in pre-test scores, indicating similar starting levels of creativity. The absence of a significant difference in post-test scores between the groups might initially imply a subtle impact. However, integrating qualitative insights from student feedback and observations paints a richer picture of the EDT curriculum's effect. These qualitative findings suggest significant enhancements in students' creative thinking and skills, pointing to the crucial role of qualitative evaluations in understanding the curriculum's comprehensive impact. For example, one student reflected, "the EDT course made me see problems in a new light. I learned to think outside the box and come up with some creative solutions that I never thought were possible before." Another student shared, "working in a team on our project helped me realize the power of collaboration in fueling creativity. Listening to my peers' ideas sparked my own creativity in ways I hadn't imagined."

This multifaceted approach to interpreting the data underscores the importance of considering both quantitative and qualitative assessments to grasp the full scope of the EDT

curriculum's influence on fostering creativity. It reveals the curriculum's deeper, possibly transformative effects on students' creative capacities, beyond what conventional metrics can reveal.

4.2.4.2 Creativity results

To evaluate student creativity in both experimental and control groups, we employed the TTCT verbal test, applying specific scoring criteria for three key dimensions of creativity: (1) Fluency: This measures the ability to generate many ideas or solutions to a problem. In our assessment, fluency was quantified by tallying the number of relevant, non-repetitive responses provided by a student. Each unique response contributed one point toward the fluency score, emphasizing the student's capacity for ideational productivity. (2) Flexibility: This evaluates the ability to produce ideas across a spectrum of categories, reflecting the student's adaptability and breadth of thinking. Flexibility was scored by identifying the diversity in the categories of effective responses, with repetitions excluded. Each distinct category identified in a student's responses was awarded one point, highlighting the variety in their creative thinking. (3) Originality: It assesses the uniqueness or novelty of the ideas generated. It was measured by the uncommonness of the responses, with points allocated based on the rarity of the ideas relative to the normative data set. Responses considered novel or unique (those less frequently encountered) received higher scores, illustrating the student's capacity for original thought. A response frequency database was established for scoring: responses with a frequency above 20% scored 0 points, those with a frequency of 5–19% scored 1 point, 2–4% scored 2 points, and those below 2% scored 3 points.

To ensure the validity and reliability of the scoring, six experienced raters form the developmental psychology research lab in our institute were recruited and trained to use the standardized scoring criteria for the students' verbal tests. The Kendall's W coefficient analysis played a pivotal role in evaluating rater reliability. The study involved six raters, who assessed the TTCT verbal test responses of both the experimental and control groups. The results showed that for the experimental group's pre-test, the Kendall's W coefficient was 0.424 ($p < 0.01$), and for the post-test, it was 0.190 ($p < 0.01$). In the control group, the pre-test coefficient was 0.102 ($p < 0.01$), and for the post-test, it was 0.165 ($p < 0.01$). These significant correlations indicate a strong agreement among the raters, confirming that the scoring was consistent and reliable across different evaluators. The presence of such high agreement levels is crucial as it ensures the validity of the study's findings, affirming that the changes observed in the students' creativity scores are reflective of the curriculum's impact and not due to variability in scoring methods.

We employed the paired sample T-test to analyze the creativity scores of both the experimental and control groups before and after the intervention. This statistical approach was crucial in determining the effectiveness of the EDT curriculum on enhancing student creativity.

In the experimental group, a significant difference was observed between the pre-test and post-test scores. This indicates a substantial improvement in the creativity scores following the EDT intervention. The post-test scores were significantly higher compared to the pre-test scores, demonstrating the positive impact of the curriculum on enhancing student creativity. Contrastingly, in the control group, the creativity scores showed a significant decrease from the pre-test to the post-test. This difference underscores the specific influence of the EDT curriculum in elevating creativity scores, as opposed to natural variances over time. These findings highlight the effectiveness of the Empathy Design Thinking curriculum in fostering creativity among primary school students. The significant improvement in the experimental group's post-test scores compared to the control group's scores validates the curriculum's role in enhancing creative thinking abilities. This analysis provides strong evidence supporting the benefits of incorporating the 4E principles in primary education to boost creativity and innovative thinking.

The findings revealed significant differences in the scores for Fluency and Flexibility between the experimental and control groups. Specifically, the experimental group showed a marked improvement in both Fluency and Flexibility scores post-intervention. This indicates that the EDT curriculum effectively enhanced the students' ability to generate a diverse range of ideas (Fluency) and to approach problems from various perspectives (Flexibility). The notable increase in these scores in the experimental group, as compared to the control group, underscores the curriculum's role in fostering these vital aspects of creative thinking.

In contrast, the scores for Originality did not show a significant difference between the pre-test and post-test for both groups. This suggests that while the EDT curriculum had a substantial impact on enhancing certain aspects of creativity, its influence on Originality, which involves the generation of novel and unique ideas, might require further exploration. This could be due to the nature of the tasks or the duration of the intervention, which might not have been sufficient to effect a significant change in this specific aspect of creativity. The absence of significant change in Originality also opens avenues for future curriculum development. It suggests a need for a more focused approach or additional strategies within the EDT framework that specifically target the enhancement of original thinking. Incorporating elements that encourage risk-taking and the exploration of unique ideas could be potential areas to explore in future iterations of the curriculum.

4.2.4.3 Empathy scores analysis

Empathy, central to the curriculum and essential for nurturing design thinking and making, was defined as the capacity to understand and share the feelings of others. To assess the curriculum's effectiveness in enhancing this crucial capacity, we measured students' empathy scores using the TEQ. This evaluation was integral in determining the curriculum's success in fostering a deeper empathetic understanding among students. The paired sample T-test analysis for empathy scores in both the experimental and control groups revealed no significant difference between the pre-test and post-test scores. Both groups exhibited a slight increase in empathy scores post-intervention, but this change was not statistically significant.

These results suggest that while the EDT curriculum may have positively influenced the students' ability to empathize, the impact was not strong enough to be reflected in a significant change in the scores. This could be due to various factors such as the nature of the curriculum, the methods used to measure

empathy, or the duration of the intervention. The relatively small change in empathy scores also points to the complexity of measuring and influencing empathetic behaviors, which often require longer-term engagement and more detailed approaches. The findings highlight the need for further exploration and potential refinement of the curriculum to more effectively nurture empathy among students. This could involve integrating more targeted activities that specifically focus on developing empathetic understanding, or extending the duration of the curriculum to allow for deeper engagement with empathy-related concepts. Additionally, employing more sensitive tools for measuring empathy might provide a clearer picture of the curriculum's impact in this area.

5 Educational implications

The study's findings on the EDT curriculum not only affirm its effectiveness but also provide expanded implications for various educational domains. These implications are critical for understanding how the curriculum can influence future curriculum development, teacher training, and educational policy. The implications suggest a transformative potential across various levels of education. By adopting the 4E principles, educational systems can foster a generation of learners equipped with the creative and empathetic skills necessary to navigate and contribute positively to an increasingly complex world. These implications provide a roadmap for future educational innovations and reforms, highlighting the critical role of empathy and creativity in education.

5.1 Expanding curriculum development with the 4E principles

The integration of the 4E principles into curriculum development marks a significant evolution in educational strategy. This approach transcends traditional methods by fostering a deeper connection between the curriculum and real-world applications. It emphasizes creating immersive learning environments that go beyond hands-on activities, aiming to instill a deeper understanding and empathy in students. This method aligns with the experiential learning and creativity fostering aspects previously discussed, where experiential learning is highlighted as a key factor in nurturing creative development. The curriculum is designed not only to educate but also to connect students with the realities and challenges of the outside world, preparing them for future professional and personal scenarios.

Incorporating empathy in the curriculum requires a shift in focus toward understanding and valuing diverse perspectives and experiences. This aspect is critical in today's globalized and interconnected environment. It's about nurturing students to become more compassionate and socially responsible individuals who can empathize with others and respond to diverse needs. The exploration and evaluation phases of the curriculum encourage students to engage in creative and critical analysis. This fosters their ability to generate innovative solutions and assess their feasibility and impact, ensuring that learning outcomes are not only creative but also practical and student-centered.

- The Experience component of the curriculum aims to immerse students in real-world contexts, enhancing their learning and empathy.
- Empathy in curriculum development is crucial for teaching students to appreciate and engage with diverse perspectives.
- Exploration and Evaluation in the curriculum promote creative and critical thinking, preparing students for future challenges.

5.2 Teacher training: deepening educational experiences

Teacher training programs need to be restructured to effectively incorporate the 4E principles. Educators play a pivotal role in creating learning environments that foster experiential learning and empathetic understanding. Training should provide teachers with the necessary tools and strategies to guide students effectively through exploration and critical evaluation phases. This involves not only imparting practical skills but also instilling an understanding of how to nurture creativity and flexible thinking. The training should emphasize the importance of creating a classroom environment where innovation and risk-taking are encouraged. This approach ensures that teachers are well-equipped to support the holistic development of students' cognitive and creative skills.

- Training programs for teachers should focus on creating learning environments that emphasize experiential learning and empathy development.
- Educators need guidance and tools to help students explore creative solutions and critically evaluate their ideas.
- Teacher training aligned with the 4E principles is essential for fostering a balanced development of cognitive and creative skills in students.

5.3 Educational policy: aligning with broader educational goals

The implications for educational policy are substantial in light of the study's findings. Integrating design thinking framework into educational systems, as seen in the 4E principles, aligns with global educational trends and supports the achievement of the SDGs. It emphasizes the importance of fostering creativity in the educational agenda. Revising policies to incorporate elements that encourage exploration, experimentation, and interaction is crucial in enhancing the creative capacities of young learners. This approach not only nurtures creativity but also prepares students to tackle the complexities and opportunities of an increasingly interconnected and complex world.

- Educational policies need to be updated to include design thinking, fostering creativity and skills in students.
- Revising educational policies to incorporate experiential learning and empathy is key for a more holistic and effective educational approach.
- Aligning educational policies with global goals like the SDGs prepares students for complex future challenges.

5.4 Broader educational practices: beyond traditional boundaries

The application of the EDT curriculum transcends primary education, offering valuable insights for higher education. By integrating EDT principles, higher education curricula can achieve a harmonious balance between technical skills and empathetic, human-centered design (HCD). In technical fields, the focus is often heavily skewed toward technical skills and theoretical knowledge. The EDT approach, however, advocates for a more rounded educational experience. It emphasizes understanding and responding to human needs in the design process, crucial for developing solutions that are technically sound and empathetically designed. This shift toward a more holistic educational approach ensures that technical proficiency is complemented by a deep understanding of HCD. This approach is particularly crucial in fields like engineering psychology, where understanding human behavior and experience is key.

- EDT in higher education can balance technical expertise with empathetic design.
- A focus on empathy and student-centered approaches prepares students for holistic creativity.
- Applying EDT in fields like engineering psychology cultivates professionals skilled in both technology development and HCD.

6 Conclusions, limitations, and future research

6.1 Conclusions

The investigation into the EDT curriculum within the context of primary education has revealed substantial findings, contributing significantly to the field of educational development. The study's foremost achievement is the effective incorporation of the 4E principles—Experience, Empathy, Exploration, and Evaluation—into the educational curriculum. This integration has demonstrably enhanced the creative capabilities of students, indicating a positive shift in their cognitive and innovative skills. The study's success in adapting the curriculum into a more compact, modular format has been noteworthy. This adaptation has not only been practical but also seamlessly fits within the constraints of the current educational system, suggesting a viable model for curriculum restructuring that does not compromise the depth and quality of education. In addition, this research underscores the pivotal role of empathy in education. The study's emphasis on empathy as a core component of the curriculum aligns with contemporary global educational objectives and trends, advocating for a more empathetic and holistic approach to learning. This aspect of the research echoes the increasing global emphasis on empathy and its importance in fostering not just academic excellence but also emotional intelligence and social understanding among students. The findings reinforce the concept that education should extend beyond traditional academic boundaries to include comprehensive development, preparing students to meet the challenges of a rapidly evolving global society.

6.2 Limitations

This study yields significant insights but encounters specific limitations. Foremost among these is its targeting of a particular age group within a distinct educational setting, which may narrow the scope of our findings' broader application. The intervention's short duration and its concentrated theme of space exploration could also constrain our understanding of its potential to foster original creative thinking. Our reliance on traditional assessment methods to measure complex attributes such as creativity and empathy may not capture the full extent of these skills. Another important consideration is the timeframe of the study. Due to the students' substantial workload and the complexities surrounding educational policy reform, we were unable to extend the duration of our study. This limitation suggests that the long-term impacts of the intervention remain an open question, underscoring the necessity for further research to explore the enduring effects of the curriculum over more extended periods.

6.3 Future research

The findings from our study open several exciting avenues for further research. Exploring the use of artificial intelligence (AI) and NeuroDesign to enhance curricula focused on empathy, as highlighted by Grudin (2009) and Ohashi et al. (2022), is a promising direction. AI has the potential to customize learning experiences to meet individual student needs and interests, offering a path to more personalized education. Similarly, NeuroDesign, which combines cognitive neuroscience with design principles, could provide deeper insights into how students interact with and respond to educational materials. Future studies should also investigate applying the 4E principles in various cultural and educational contexts to assess their effectiveness and appeal broadly. Expanding research to include a wider range of ages and using long-term study designs would help us better understand the lasting effects of the EDT curriculum. Moving forward with these research directions will help overcome the limitations of the current study and broaden our understanding of how the curriculum performs in different educational environments and with diverse student groups.

Data availability statement

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

Ethics statement

The studies involving humans were approved by Beijing Normal University. The studies were conducted in accordance with the local legislation and institutional requirements. Written informed consent for participation in this study was provided by the participants' legal guardians/next of kin. Written informed consent was obtained from the individual(s), and minor(s)' legal guardian/next of kin, for the publication of any potentially identifiable images or data included in this article.

Author contributions

WL: Writing – review & editing, Writing – original draft, Conceptualization. RH: Writing – original draft, Conceptualization. JW: Writing – review & editing, Conceptualization. YC: Writing – review & editing, Conceptualization. TO: Writing – original draft, Conceptualization. BL: Writing – review & editing, Data curation. YL: Writing – original draft, Data curation. DQ: Writing – original draft, Investigation. RY: Writing – original draft, Software. JZ: Writing – original draft, Conceptualization. AA: Writing – review & editing, Conceptualization. LL: Writing – review & editing, Conceptualization.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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References

Akin, Ö., and Akin, C. (1996). Frames of reference in architectural design: analysing the hyperacclamation (Aha-!). *Des. Stud.* 17, 341–361. doi: 10.1016/S0142-694X(96)00024-5

Almeida, L. S., Prieto, L. P., Ferrando, M., Oliveira, E., and Ferrándiz, C. (2008). Torrance test of creative thinking: the question of its construct validity. *Think. Skills Creat.* 3, 53–58. doi: 10.1016/j.tsc.2008.03.003

Amabile, T. M. (1983). The social psychology of creativity: a componential conceptualization. *J. Person. Soc. Psychol.* 45:357. doi: 10.1037/0022-3514.45.2.357

Armstrong, C. E. (2016). Teaching innovation through empathy: design thinking in the undergraduate business classroom. *Manage. Teach. Rev.* 1, 164–169. doi: 10.1177/2379298116636641

Boeren, E. (2019). Understanding Sustainable Development Goal (SDG) 4 on "quality education" from micro, meso and macro perspectives. *Int. Rev. Educ.* 65, 277–294. doi: 10.1007/s11159-019-09772-7

Bush, S., Edelen, D., Roberts, T., Maiorca, C., Ivy, J. T., Cook, K. L., et al. (2024). Humanistic STE (A) M instruction through empathy: leveraging design thinking to improve society. *Pedagogies* 19, 60–79. doi: 10.1080/1554480X.2022.2147937

Claxton, A. F., Pannells, T. C., and Rhoads, P. A. (2005). Developmental trends in the creativity of school-age children. *Creat. Res. J.* 17, 327–335. doi: 10.1207/s15326934crj1704_4

Cobo, C. (2013). Skills for innovation: Envisioning an education that prepares for the changing world. *Curric. J.* 24, 67–85. doi: 10.1080/09585176.2012.744330

Cross, N. (2007). Forty years of design research. *Des. Stud.* 1, 1–4. doi: 10.1016/j.destud.2006.11.004

Cross, N. (2023). Design thinking: what just happened? *Des. Stud.* 86:101187. doi: 10.5040/9781350305090

Dorst, K., and Cross, N. (2001). Creativity in the design process: co-evolution of problem–solution. *Des. Stud.* 22, 425–437. doi: 10.1016/S0142-694X(01)00009-6

Dotson, M. E., Alvarez, V., Tackett, M., Asturias, G., Leon, I., and Ramanujam, N. (2020). Design thinking-based STEM learning: Preliminary results on achieving scale and sustainability through the Ignite model. *Front. Educ.* 5:14. doi: 10.3389/feduc.2020.00014

Dym, C. L., Agogino, A. M., Eris, O., Frey, D. D., and Leifer, L. J. (2005). Engineering design thinking, teaching, and learning. *J. Eng. Educ.* 94, 103–120. doi: 10.1002/j.2168-9830.2005.tb00832.x

Facer, K., and Sandford, R. (2010). The next 25 years? Future scenarios and future directions for education and technology. *J. Comput. Assist. Learn.* 26, 74–93. doi: 10.1111/j.1365-2729.2009.00337.x

Gardner, H. E. (2011). *Frames of Mind: The Theory of Multiple Intelligences.* London: Basic books.

Gero, J. S., and Milovanovic, J. (2020). A framework for studying design thinking through measuring designers' minds, bodies and brains. *Des. Sci.* 6:e19. doi: 10.1017/dsj.2020.15

Goldman, S., Carroll, M., and Royalty, A. (2009). "Destination, imagination and the fires within: design thinking in a middle school classroom," in *Proceedings of the Seventh ACM Conference on Creativity and Cognition,* 371–372. doi: 10.1145/1640233.1640306

Gray, C. M., and Exter, M. E. (2023). A design sprint towards a four-year curriculum in transdisciplinary studies. *Int. J. Des. Learn.* 14, 70–87. doi: 10.14434/ijdl.v14i1.35194

Grudin, J. (2009). AI and HCI: two fields divided by a common focus. *AI Magaz.* 30, 48–48. doi: 10.1609/aimag.v30i4.2271

Guaman-Quintanilla, S., Everaert, P., Chiluiza, K., and Valcke, M. (2023). Impact of design thinking in higher education: a multi-actor perspective on problem solving

and creativity. *Int. J. Technol. Des. Educ.* 33, 217–240. doi: 10.1007/s10798-021-09724-z

Guilford, J. P. (1967). Creativity: yesterday, today and tomorrow. *J. Creat. Behav.* 1, 3–14. doi: 10.1002/j.2162-6057.1967.tb00002.x

Han, J., Park, D., Hua, M., and Childs, P. R. (2021). Is group work beneficial for producing creative designs in STEM design education? *Int. J. Technol. Des. Educ.* 15, 1–26. doi: 10.1007/s10798-021-09709-y

Hausfather, S. J. (1996). Vygotsky and schooling: creating a social context for learning. *Action Teach. Educ.* 18, 1–10. doi: 10.1080/01626620.1996.10462828

He, W., Yan, J., Wang, C., Liao, L., and Hu, X. (2023). Exploring the impact of the design thinking model on fifth graders' creative self-efficacy, situational interest, and individual interest in STEM education. *Think. Skills Creat.* 50:101424. doi: 10.1016/j.tsc.2023.101424

Heylighen, A., and Dong, A. (2019). To empathise or not to empathise? Empathy and its limits in design. *Des. Stud.* 65, 107–124. doi: 10.1016/j.destud.2019.10.007

Hsia, L. H., Lin, Y. N., and Hwang, G. J. (2021). A creative problem solving-based flipped learning strategy for promoting students' performing creativity, skills and tendencies of creative thinking and collaboration. *Br. J. Educ. Technol.* 52, 1771–1787. doi: 10.1111/bjet.13073

Jia, X., Hu, W., Cai, F., Wang, H., Li, J., Runco, M. A., et al. (2017). The influence of teaching methods on creative problem finding. *Think. Skills Creat.* 24, 86–94. doi: 10.1016/j.tsc.2017.02.006

Kangas, M. (2010). Creative and playful learning: learning through game co-creation and games in a playful learning environment. *Think. Skills Creat.* 5, 1–15. doi: 10.1016/j.tsc.2009.11.001

Kannengiesser, U., and Gero, J. S. (2019). Design thinking, fast and slow: a framework for Kahneman's dual-system theory in design. *Des. Sci.* 5:e10. doi: 10.1017/dsj.2019.9

Kermavnar, T., and Desmet, P. M. (2024). Technology and meditation: exploring the challenges and benefits of a physical device to support meditation routine. *Multim. Technol. Inter.* 8:9. doi: 10.3390/mti8020009

Kim, K. H. (2006). Can we trust creativity tests? A review of the Torrance Tests of Creative Thinking (TTCT). *Creat. Res. J.* 18, 3–14. doi: 10.1207/s15326934crj1801_2

Klapwijk, R., and van Doorn, F. (2015). Contextmapping in primary design and technology education: a fruitful method to develop empathy for and insight in user needs. *Int. J. Technol. Des. Educ.* 25, 151–167. doi: 10.1007/s10798-014-9279-7

Kouprie, M., and Visser, F. S. (2009). A framework for empathy in design: stepping into and out of the user's life. *J. Eng. Des.* 20, 437–448. doi: 10.1080/09544820902875033

Lee, H. K., and Park, J. E. (2021). Designing a new empathy-oriented prototyping toolkit for the design thinking process: creativity and design sensibility. *Int. J. Art Des. Educ.* 40, 324–341. doi: 10.1111/jade.12345

Leifer, L. J., and Steinert, M. (2011). Dancing with ambiguity: Causality behavior, design thinking, and triple-loop-learning. *Inform. Knowl. Syst. Manag.* 10, 151–173. doi: 10.3233/IKS-2012-0191

Levy, M., and Hadar, I. (2024). Learning to empathize with users through design thinking in hybrid mode: insights from two educational case studies. *J. Syst. Softw.* 207:111831. doi: 10.1016/j.jss.2023.111831

Lewrick, M., Link, P., and Leifer, L. (2018). *The Design Thinking Playbook: Mindful Digital Transformation of Teams, Products, Services, Businesses and Cosystems*. New York: John Wiley and Sons.

Li, X., Chen, J., and Fu, H. (2024). The roles of empathy and motivation in creativity in design thinking. *Int. J. Technol. Des. Educ.* 20, 1–20. doi: 10.1007/s10798-023-09869-z

Liu, W., Fu, Z., Zhu, Y., Li, Y., Sun, Y., Hong, X., et al. (2024). Co-making the future: Crafting tomorrow with insights and perspectives from the China-US young maker competition. *Int. J. Technolo. Des. Educ.* 2024, 1–21. doi: 10.1007/s10798-024-09887-5

Liu, W., Zhu, Y., Liu, M., and Li, Y. (2021). Exploring maker innovation: A transdisciplinary engineering design perspective. *Sustainability* 14:295. doi: 10.3390/su14010295

Maher, M. L., and Poon, J. (1996). Modeling design exploration as co-evolution. *Comput. Aided Civil Infrastr. Eng.* 11, 195–209. doi: 10.1111/j.1467-8667.1996.tb00323.x

Mansilla, V. B., and Wilson, D. (2020). What is global competence, and what might it look like in Chinese schools? *J. Res. Int. Educ.* 19, 3–22. doi: 10.1177/1475240920914089

Marsden, N., and Wittwer, A. (2022). Empathy and exclusion in the design process. *Front. Hum. Dyn.* 4:1050580. doi: 10.3389/fhumd.2022.1050580

Martin, L., and Murphy, C. T. (2022). Tinkering in the time of COVID: Lessons from educators' efforts to facilitate playful tinkering through online learning. *Int. J. Play* 11, 127–144. doi: 10.1080/21594937.2022.2069350

Matthews, J., and Wrigley, C. (2017). Design and design thinking in business and management higher education. *J. Learn. Des.* 10, 41–54. doi: 10.5204/jld.v9i3.294

Montero, J. (2023). Developing empathy through design thinking in elementary art education. *Int. J. Art Des. Educ.* 42, 155–171. doi: 10.1111/jade.12445

Niemi, H., and Liu, J. (2021). AI in learning: intelligent digital tools and environments for education. *J. Pacific Rim Psychol.* 15:18344909211038110. doi: 10.1177/18344909211038110

Niu, S. J., Luo, J., Niemi, H., Li, X., and Lu, Y. (2022). Teachers' and students' views of using an AI-aided educational platform for supporting teaching and learning at Chinese schools. *Educ. Sci.* 12:858. doi: 10.3390/educsci12120858

Norman, D. A. (2023). *Design for a Better World: Meaningful, Sustainable, Humanity Centered*. London: MIT Press.

Ohashi, T., Auernhammer, J., Liu, W., Pan, W., and Leifer, L. (2022). NeuroDesignScience: systematic literature review of current research on design using neuroscience techniques. *Des. Comput. Cogn.'*20, 575–592. doi: 10.1007/978-3-030-90625-2_34

Pande, M., and Bharathi, S. V. (2020). Theoretical foundations of design thinking–A constructivism learning approach to design thinking. *Think. Skills Creat.* 36:100637. doi: 10.1016/j.tsc.2020.100637

Phan, P., Zhou, J., and Abrahamson, E. (2010). Creativity, innovation, and entrepreneurship in China. *Manag. Organiz. Rev.* 6, 175–194. doi: 10.1111/j.1740-8784.2010.00181.x

Pivonka, A. C., Makary, L., and Gray, C. M. (2024). Organizing metaphors for design methods. *Int. J. Technol. Des. Educ.* 2024, 1–19. doi: 10.1007/s10798-024-09880-y

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

Qian, H., Walker, A., and Chen, S. (2023). The 'double-reduction' education policy in China: three prevailing narratives. *J. Educ. Policy* 2023, 1–20. doi: 10.1080/02680939.2023.2222381

Reshetnikova, M. S. (2018). Innovation and entrepreneurship in China. *Eur. Res. Stud.* 21, 506–515. doi: 10.35808/ersj/1079

Resnick, M. (2017). *Lifelong Kindergarten: Cultivating Creativity Through Projects, Passion, Peers, and Play*. New York: MIT press. doi: 10.7551/mitpress/11017.001.0001

Resnick, M., Maloney, J., Monroy-Hernández, A., Rusk, N., Eastmond, E., Brennan, K., et al. (2009). Scratch: programming for all. *Commun. ACM* 52, 60–67. doi: 10.1145/1592761.1592779

Resnick, M., and Rusk, N. (2020). Coding at a crossroads. *Commun. ACM* 63, 120–127. doi: 10.1145/3375546

Rittel, H. W., and Webber, M. M. (1973). Dilemmas in a general theory of planning. *Policy Sci.* 4, 155–169. doi: 10.1007/BF01405730

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

Saggar, M., Volle, E., Uddin, L. Q., Chrysikou, E. G., and Green, A. E. (2021). Creativity and the brain: an editorial introduction to the special issue on the neuroscience of creativity. *NeuroImage* 231:117836. doi: 10.1016/j.neuroimage.2021.117836

Schön, D. A. (1992). Designing as reflective conversation with the materials of a design situation. *Knowl. Based Syst.* 5, 3–14. doi: 10.1016/0950-7051(92)90020-G

Siew, N. M., and Ambo, N. (2020). The scientific creativity of fifth graders in a STEM project-based cooperative learning approach. *Probl. Educ. 21st Cent.* 78, 627–643. doi: 10.33225/pec/20.78.627

Simon, H. A. (1973). The structure of ill structured problems. *Artif. Intell.* 4, 181–201. doi: 10.1016/0004-3702(73)90011-8

So, I. (1964). Cognitive development in children: piaget development and learning. *J. Res. Sci. Teach.* 2, 176–186. doi: 10.1002/tea.3660020306

Spreng, R. N., McKinnon, M. C., Mar, R. A., and Levine, B. (2009). The toronto empathy questionnaire: scale development and initial validation of a factor-analytic solution to multiple empathy measures. *J. Person. Assess.* 91, 62–71. doi: 10.1080/00223890802484381

Stephan, C. (2023). The passive dimension of empathy and its relevance for design. *Des. Stud.* 86:101179. doi: 10.1016/j.destud.2023.101179

Teng, J., Yang, Z., Yu, M., Crowley, C. B., and Jing, X. (2024). Chinese primary school teachers' working time allocation after the enactment of the "Double Reduction" policy: a mixed-methods study. *Teach. Teach. Educ.* 137:104385. doi: 10.1016/j.tate.2023.104385

Tight, M. (2021). Twenty-first century skills: meaning, usage and value. *Eur. J. High. Educ.* 11, 160–174. doi: 10.1080/21568235.2020.1835517

van Rheden, V., Harbour, E., Finkenzeller, T., and Meschtscherjakov, A. (2024). Into the rhythm: evaluating breathing instruction sound experiences on the run with novice female runners. *Multim. Technol. Inter.* 8:25. doi: 10.3390/mti8040025

Voultsos, P., Chatzinikolaou, F., Papana, A., and Deliligka, A. (2022). Reliability of Greek version of the Toronto empathy questionnaire in medical students and associations with sociodemographic and lifestyle factors. *BMC Psychol.* 10:113. doi: 10.1186/s40359-022-00824-6

Wang, D., Chen, X. Y., Ma, Z., Liu, X., and Fan, F. (2022). Has the "Double Reduction" policy relieved stress? A follow-up study on Chinese adolescents. *Child Adoles. Psychiat. Mental Health* 16:91. doi: 10.1186/s13034-022-00530-6

Xiang, M., Zhang, J., and Li, Y. (2024). "Understanding knowledge convergence in a cross-cultural online context: an individual and collective approach," in *Proceedings of the 14th Learning Analytics and Knowledge Conference,* 779–784. doi: 10.1145/3636555.3636870

Xue, E., and Li, J. (2023). What is the value essence of "double reduction" (Shuang Jian) policy in China? A policy narrative perspective. *Educ. Philos. Theory* 55, 787–796. doi: 10.1080/00131857.2022.2040481

Zhang, J., Yang, Y., Ge, J., Liang, X., and An, Z. (2023). Stimulating creativity in the classroom: examining the impact of sense of place on students' creativity and the mediating effect of classmate relationships. *BMC Psychol.* 11, 1–12. doi: 10.1186/s40359-023-01479-7