Review

Not peer-reviewed version

A Scoping Review of the Trends and Opportunities of Tangible Creativity Support Tools (T-CSTs)

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Posted Date: 1 August 2024

doi: 10.20944/preprints202407.2615.v1

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A Scoping Review of the Trends and Opportunities of Tangible Creativity Support Tools (T-CSTs)

Yimin Wang *, Mengqi Jiang and Ziqian Bai

The Hong Kong Polytechnic University; kenjiyiminwang@gmail.com

Abstract: The research of tangible creativity support tools (T-CSTs) has been increasing in recent years. However, there is a lack of review that interprets what T-CSTs trends must be considered and how challenging opinions should be broken. Hence, a focused and critical review of existing studies is necessary. This paper analyzed 86 studies related to T-CSTs following the PRISMA protocol. First, the research tendencies were extracted and provided a basic knowledge construction. Then, we extracted primary research questions, categorized the adopted design and technological solutions, and identified the researchers' hypotheses-validation. Last, we proposed research gap, challenge and potential opportunities for future researchers and designers. This review will benefit people in the fields of tangible interaction, design studies and education.

Keywords: human-computer interaction; creativity support tools; tangible interface; interaction design

1. Introduction

Creativity is the distinct and advanced cognitive capacity for human beings. It enables individuals to extend their cognitions beyond traditional constraints and empirical principles, thus generate innovative ideas (Robinson, 2008; Allen, 2018). Nevertheless, given the fact that human creativity is influenced by multiple internal factors (e.g., cognitive abilities, personality traits, motivation, etc.) and external factors (e.g., social and cultural influences, resources, environmental conditions, etc.), it is necessary to leverage design tools to alleviate limitations and facilitate effective creative output (Amabile, 1983; Csikszentmihalyi, 1996; Runco and Jaeger, 2012). With the development of human-computer interaction (HCI), the concept of Creativity Support Tools (CSTs) was generated. CSTs help individuals to refine their immature conceptions in creation (Bonnardel and Zenasni, 2010). CSTs support creativity by integrating interdisciplinary knowledge, promoting teamwork, and increasing efficiency in idea iteration phase (Shneiderman, 2009; Shneiderman, 2006; Zagalo and Branco, 2015; Derda et al., 2022). With the assistance of CSTs, traits of creative output can be improved, e.g., flexibility (Jansson and Smith, 1991), aesthetics (Zuo, 1998), appropriateness (Sternberg, 1999), novelty (Dym et al., 2005), concept (Colton et al., 2011) and originality (Runco and Jaeger, 2012).

Traditional CSTs work on a graphic user interface (GUI) (e.g., digital screen), also known as Graphic Creativity Support Tools (G-CSTs). However, the technical affordance of G-CST for supporting creative scenarios has been questioned, for its limitation generated from manipulation in pixel screens (Cheng et al., 2011; Zuckerman et al., 2013; Gutiérrez Posada et al., 2014). For instance, GUI is difficult for digitally disadvantaged groups (e.g., patients with cognitive and limbic deficits) to input effective information.

Tangible User Interface (TUI) is a medium in which users interact with digital information in a physical environment (Ishii, 2008). In HCI, augmented bodily perception can reinforce information processing and contribute to mental intelligence (Foglia and Wilson, 2013). On the one hand, TUI heightened the capacity of sensing and manipulating the physical world, facilitated interaction with the digital world by leveraging the affordance of physical objects, surfaces, and spaces. On the other hand, TUI also enhances human's naturalness of interaction by materializing digital data in physical world (MIT Media Lab, 2022). Overall, TUI provides users with higher levels of realism, physical interaction, and rich sensory experiences (e.g., multi-touch, kinesthetic, voice-controlled, haptic, and adaptive interaction) (Zuckerman et al., 2013).

With the effective integration of TUI, the performance of CST can be improved, such as more embodied cognition (El-Zanfaly et al., 2022), flexible manipulation (Le Goc et al., 2020), and high technical affordance (Alex et al., 2021), thus, the interest of Tangible Creativity Support Tools (T-CSTs) is emerging. However, T-CSTs' transformative development might not have received enough attention. Besides, T-CSTs lack well-defined research framework, making conducting a systematic review difficult. Here, we proposed two research questions:

- **RQ 1**: *What are the research trends of T-CSTs?*
- **RQ 2**: *What are the future T-CSTs' research opportunities?*

To address these two questions, an analysis of the research question generation, artifact design, technological actualization, evaluation, summarization and critical comments of related T-CSTs research, were given. From this, current trends and potential future opportunities of T-CSTs were identified to assist researchers and designers in their early-stage exploration.

2. The Collection of Research Samples

2.1. Methodology

Research samples were collected following the PRISMA protocol (Moher et al., 2009) (see Figure 1). Details of the sample selection are provided below.

Database choice. To search for research samples, we utilized a range of databases, including Web of Science, ACM Digital Library, IEEE Xplore, Engineering Village, Science Direct, and other relevant sources. Selecting Web of Science for our search allowed us to access a comprehensive citation database covering a broad range of scientific disciplines, including computer science, engineering, and social sciences. This ensured that we could obtain research samples across diverse topics, making our study more comprehensive. The ACM Digital Library and IEEE Xplore databases contain a significant amount of design and empirical research related to T-CSTs, with a focus on sample designs that are well-aligned with the research style of HCI. Additionally, the remaining databases utilized in this study contain numerous research samples that were conducted using comprehensive and rigorous methods, making them important to consider. Through the use of these databases in combination, we were able to identify as many eligible research samples as possible for screening in this study.

Searching strategy. The following terms and connectors were used for the query: ('Creativity Support Tools' OR 'Creative Enhancement' OR 'Creative Reinforcement' OR 'Creative Empowerment' OR 'Creative Improvement') AND Interaction, technology, AND technique. The initial search was carried out on September 25, 2021, and the second search for Creativity support systems / Tangible / Natural user interfaces was finished on June 22, 2022.

Screening criteria. Our screening criteria is shown in Figure 1. 1258 papers were found in Web of Science (*N=277*), Engineering Village (*N=273*), ACM Digital library (*N=256*), IEEE Xplore (*N=125*), Science Direct (*N=70*), and Others (*N=257*). After removing duplicates, 905 accessible documents remained. To avoid inaccurate titles (i.e., technical enhancement of comprehensive learning ability), we further screened the samples according to the abstracts and 470 papers were removed. Then, we reviewed the complete text of rest samples carefully, leaving 61 papers that meet the following criteria: 1) The study must include detailed TUI-based prototypes. 2) The study should have well-defined research question, objective, concept, experiment, detailed data, and result. 4) The studies must be published in journals or conferences. Further, to ensure a balanced collection of research samples, we employed two methods to supplement the sample size. On the one hand, we added potential samples that were cited by researchers in the existing collected sample set (*N=10*). On the other hand, we utilized other approaches to add to the screening list, such as selecting appropriate samples from the authors' other research projects in the existing collected sample set (*N=15*). As a result, this research contained 86 T-CSTss work, 64.8% are conference papers, and 35.2% are journal publications, all in English (see Table A1 in Appendix for detailed information on collected samples).

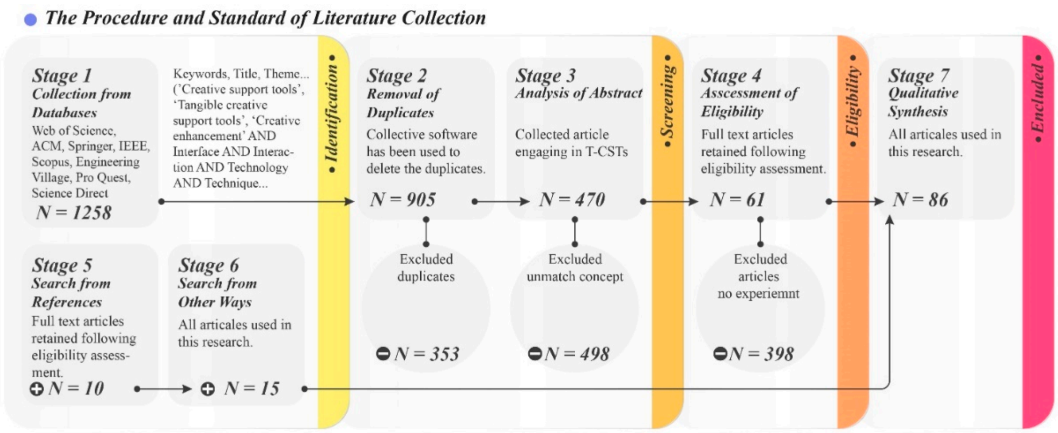

Figure 1. The procedure and screening criteria of literature collection.

2.2. Overview of Publication

The screened samples dated back to 2011, and approximately 70% of the papers were published in the past five years (see Figure 2A) and showed positively growing tendency. The most referred topic is education (*N=29*), other, e.g., art (*N=16*), business (*N=11*), work (*N=10*) and life (*N=3*) were also covered (see Figure 2B). Moreover, the forms of technical presentation of samples were extracted in Figure 2C. The Internet of things (IoT) related prototypes and toolkits (*N=25*), virtual reality/augmented reality (VR/AR) (*N=20*), and social robots (*N=17*) were mainstream solutions.

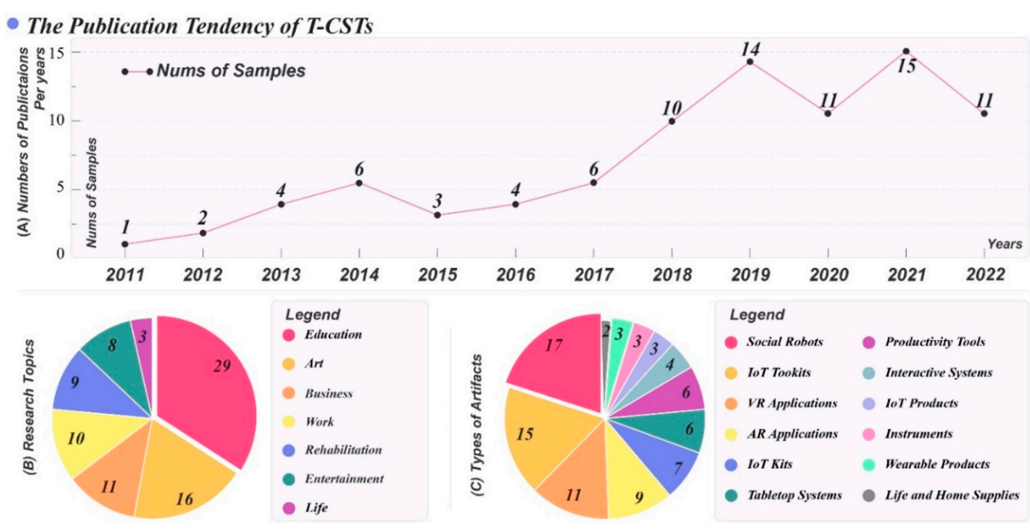

Figure 2. The publication tendency of T-CSTs, (A) numbers of publications per year, (B) research topics, (C) forms of artifacts.

Social Network Analysis (SNA) method was adopted (Barnes, 1969) to investigate the knowledge structure of T-CSTs. The keywords of these papers were chosen to build the text dataset. We de-duplicated the raw data and reduced their tense and lexicon. Some technology nouns and concepts were also merged. Further, the analyzed result was visualized using Gephi 0.9.2 (Bastian et al., 2009) (see Figure 3). The SNA results showed three development stages of T-CSTs with three years as a period.

In the **initial period** (2011-2014), T-CSTs researchers mainly focused on *Work*, *Business,* and *Art* topics. The emergence of nodes like *Materiality, Augmented Multi-Touch, Multi-modal, and Natural User*

 doi:10.20944/preprints202407.2615.v1

Interface, among others, indicated that researchers began to focus on the materiality of TUI and introduced it into the construction of CSTs (see labels in the blue rounded rectangle in Figure 3A). Then, T-CSTs established the basic knowledge structure in the **transitional period** (2015-2018), T-CSTs' research process became more abundant with interdisciplinary collaboration, as shown on the labels in the yellow rounded rectangle in Figure 3B. The design form of prototypes became more diversified, such as *Sensor-Based Furniture, Motion Picture and Analysis*, and *Sketch-based Modeling*. Considerable research related to *Rehabilitation* and *Education* showed that TUI served digitally disadvantaged users.

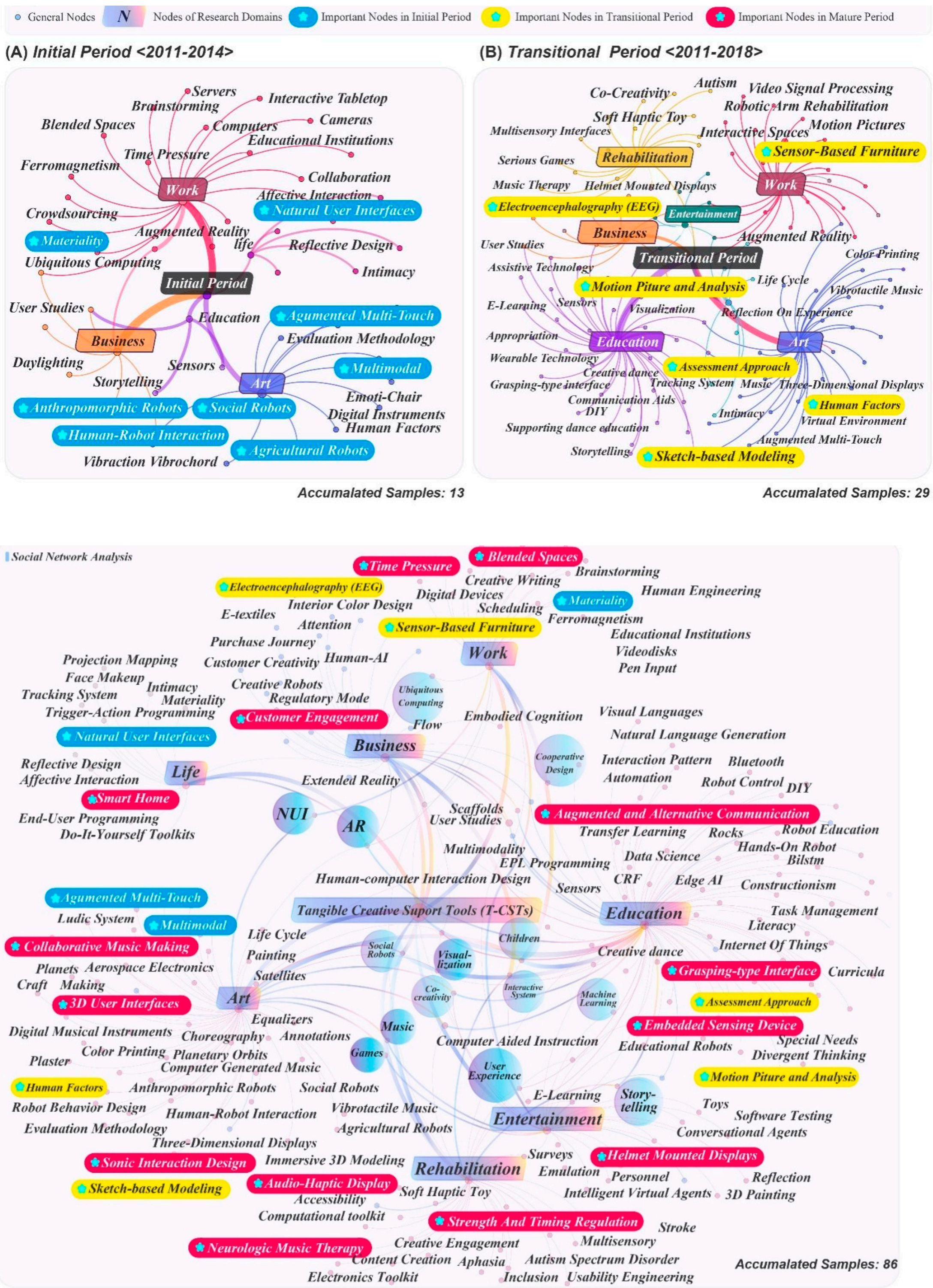

Figure 3. The analysis of knowledge content of T-CSTs in Initial and transitional Periods. (A) initial period (2011-2014), (B) transitional period (2011-2018), (C) mature period (2019-2022).

In the **mature period** (2019-2022), the knowledge structure has been further developed in-depth. The emergence of buzzwords, such as *Smart Home* and *Helmet Mounted Display*, indicated that non-specialized domains, such as *Entertainment* and *Life,* became the emerging interest of T-CSTs. Furthermore, many research of the *Art* and *Education* engaged in diverse technical forms, such as *3D User Interface, Collaborative Music Making, Sonic Interaction Design, Augmented and Alternative Communication, Grasping-type interface,* and *Embedded Sensing Devices* (see labels in the blue rounded rectangle in Figure 3C). Besides, *Nature User Interface (NUI), Visualization, Machine Learning,* and *AR* received much attention regarding technological solutions.

3. The Analysis of Research Construction

3.1. Theoretical Frameworks of T-CSTs Research

Theoretical frameworks for enhancing creativity offer analytical approaches to examine research samples. such as the *4P Framework* (Rhodes, 1961), the *Psychological Model of Creativity* (Sternberg, 2021), and the *Creativity 4.0 Model* (Bruno and Canina, 2019), etc., as shown in Figure 4. Research samples can be broadly classified into five categories: **external influence**, **capable affordance**, **behavioral stimulation**, **thinking space**, and **conceptual expression**.

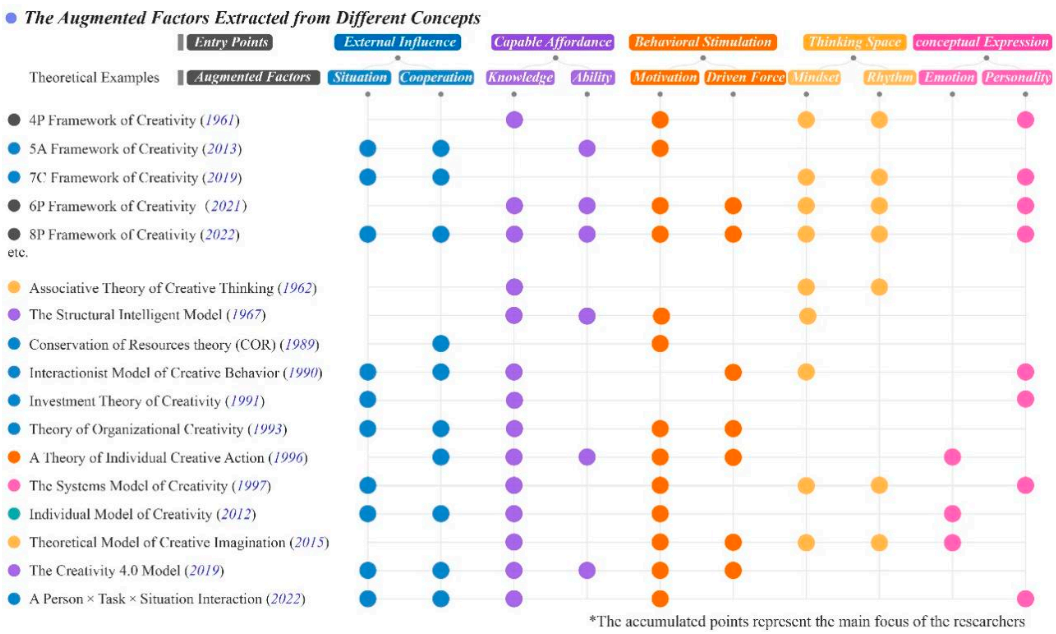

Figure 4. The entry points and augmented factors extracted from multiple theoretical models.

3.2. Research Aims

These studies revolved different research aims, respectively. Most studies focused on the **external influence** (N=33) of T-CSTs, emphasizing the integration of dispersed creative resources through improving team collaboration, so called *organizational creativity* (Ehrenberg et al., 2018, Alves-Oliveira et al., 2020; Thorn, 2021). They researched on how technology encouraged collective activities in innovative culture, equal opportunities, cross-functional collaboration, agile management, resource integration, and inclusive environment (Men et al., 2018; Le Goc et al., 2020; Blanco et al., 2022; Schmill et al., 2022).

Many studies concentrated on leveraging T-CSTs to increase **capable affordance** (N=26) for digitally disadvantaged users. The affordance, natural interaction and cognitive load of T-CSTs were

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their primary exploration (Yamaoka and Kakehi, 2013; Lee et al., 2017; Endow et al., 2022, Costa et al., 2019; Chen et al., 2021).

For **behavioral stimulation** (N=12), these studies employed playfulness and positive experience to stimulate user engagement in creative activities (Baur et al., 2018; Belakova et al., 2021). How to leverage the rich physical and sensory experiences of T-CSTs to create a more immersive and engaging environment became their aim.

Several studies aimed at **design thinking** (N=9), researchers compared how T-CSTs assisted creators' diversified thinking processes. Representative topics mainly included STEAM-related approaches, e.g., hands-on practice (Thieme et al., 2011; Jou and Wang, 2015; Kim, 2020; Hubbard et al., 2022), verbal creativity (Alves-Oliveira et al., 2020; Hu et al., 2021; Thorn, 2021), storytelling guidance (Cullen and Metatla, 2019; Hirsch et al., 2021; Somma et al., 2021).

For **conceptual expression** (N=5), some work explored the technical forms, regarding the effectiveness improvement, uniqueness, and diversity of creative expressions. Their topics centered on expression styles and immersive technologies, such as improv creative behaviors (Yamaguchi et al., 2017; Campos et al., 2014) and multi-sensory environments (Seo et al., 2017; Yang et al., 2018; Cullen and Metatla, 2019; Sabuncuoglu, 2020).

3.3. Design Solutions of T-CSTs

This section revealed the design solutions of T-CSTs, as visualized in Figure 5.

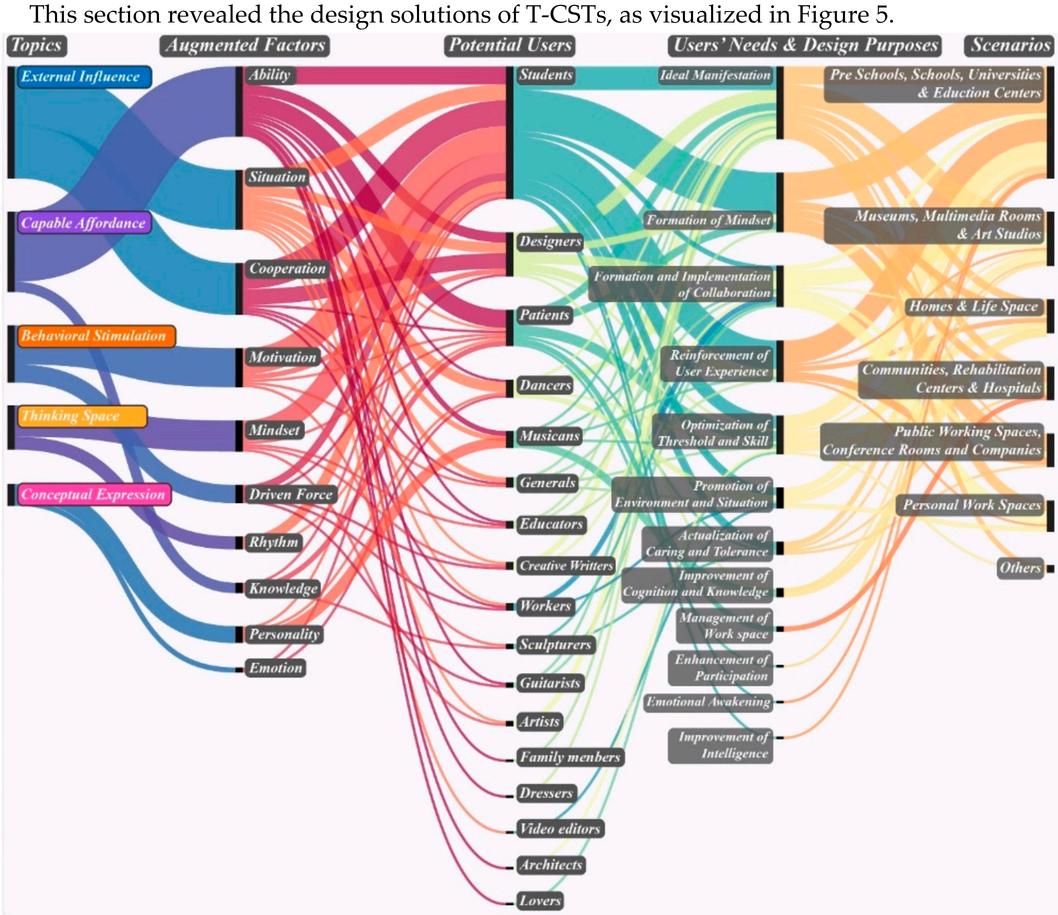

Figure 5. Analysis of artifact design.

TUI optimized external influence for creativity training, aimed at improving their collaboration. Various designs are *Co-creation*s, e.g., AR-based system for effective communication (Jessen et al., 2020), tangible storytelling tools for rehabilitation (Neate et al., 2020; Cullen and Metatla, 2019). Some artifacts developed embodied visual environments (Yang et al., 2018; Costa et al., 2019; Lottridge, 2022).

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Researchers optimized the affordance for non-professionals and beginners by designing more user-friendly components to reduce recognition burden, such as lowering the threshold of expressing with electronic textiles design (Endow et al., 2022), improving the accuracy of physical modeling for architectural exploration (Nasman and Cutler, 2013), and establishing the multi-sensory memory of piano beginners (Branje and Fels, 2014).

T-CSTs affected creators' engagement and behavior, especially for long-term and remote environments. For example, to encourage creative workers to manage their schedules, tangible calendar *Monomizo* was developed to cultivate reasonable working habits (Jang et al., 2019). The multi-sensory VR/AR environment was also prevalent for emotion regulation (Fujinami et al., 2018; Dube and İnce, 2019; Somma et al., 2021).

Artifacts focused on design thinking leveraged heuristic activities for creative beginners in daily lives with interactive features. *Human-robot interaction* (HRI) systems with heuristic functions (e.g., verbal guidance, behavioral imitation, and drawing) were developed for storytelling training (Alves-Oliveira et al., 2020; Elgarf et al., 2021; Ali et al. 2021; Ali et al., 2022). IoT toolkits *PlushPal* allowed children to build machine learning-based models through interaction with customized toys (Tseng et al., 2021).

Conceptual expression studies optimized the expressive behavior of artists (e.g., musicians, dancers, and performing artists) by enhancing their emotions. For example, *TwinkleBall* (Yamaguchi et al., 2017) generated real-time music, *ImprovBot* (Rond et al., 2019) inspired improv creativity, and preference-driven computational design (Urban Davis et al., 2021; Lin et al., 2020; Guo et al., 2022).

3.4. Prototyping Technologies

To achieve the experiment and application of the design solutions, many mainstream technologies were utilized in the development process. The main solutions include social robots for instructive avatars, IoT toolkits for technological affordance, VR/AR for embedded experience, augmented tools for augmented working, and interactive tablets for collaboration.

Social robot is a co-creative agent, offers an external setting that assists creative process, such as the definition of creative space, evaluation of similar examples, consideration of alternative schemes, and engagement of creative conflict (Kahn et al., 2014; Kahn et al., 2016). Social robots equipped devices with multi-sensory input for extracting humans' creative intention, such as visual information (Cosentino et al., 2014), text information (Lin et al., 2020; Hu et al.,2021; Ali et al., 2022), and verbal information (Elgarf et al., 2021; Ali et al., 2021).

DIY toolkits assisted hands-on and concrete actualization of mental imagery by providing electronic materials to build, experiment, and reflect on their creative thinking. These toolkits include components such as moisture, force, potentiometer, ultrasonic sensors, LED, DC motor, buzzer, LCD (Somma et al., 2021), etc. Some toolkits decreased the difficulty of construction, such as *FritzBot* for conversational instruction (Chen et al., 2021), *Makey Makey (MM)* and *TronicBoard* for low-burden programming (Makela and Vellonen, 2018; Senaratne et al., 2022).

VR/AR enhanced creativity by enabling users to manipulate and engage with virtual objects and environments in a realistic and immersive manner, thereby providing new opportunities for simulating natural behaviors. Based on head-mounted devices (HMDs) and motion capture devices, users could release more unrestrained behaviors, like jumping, running, squatting, etc. Some researchers designed advanced manipulation modes, such as handle-operated 3D sketching modeling (Jackson et al., 2016; Yang et al., 2018) , gesture-based collaborative music making (Men and Bryan-Kinns, 2018; Costa et al., 2019), somatic sense-based sandbox playing (Fröhlich et al., 2018) and posture-located dancing (Lottridge et al., 2022). Several AR studies embedded GUI tools (Dube and Ince, 2019; Jessen et al., 2020; Im and Rogers, 2021) , and one utilized AR glasses (Campos et al., 2014).

Augmented tools provided accessible interfaces for idea generation and collaboration, enabling users to efficiently capture thoughts and concepts. Many tools integrated IoTs components to expand their functionality, for example, integrating gesture sensors into wearable devices (Liu et al., 2012; Tseng et al., 2021; Martelloni et al., 2021) and instruments (Law et al., 2019) , augmenting pens with accelerometer sensors (Cox and Semwal, 2020) , interactive products with physical manipulation input (Wang et al., 2014; Chen et al., 2019; Hirsch et al., 2021).

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Interactive tablets served as collaboration platforms in the creative process for human-computer and team collaboration. For example, *Sand playground* work platforms (El-Zanfaly et al., 2022) and robotic arms (Law et al., 2019) enable cooperative manipulation of physical components, while *All4One* facilitate multi-person brainstorming (Lee et al., 2017).

3.5. Evaluation of T-CSTs Solutions

The research sample experiments were 38% qualitative, 30% quantitative, and 32% mixed-method studies. The most common evaluation scenario was conducted in workshops, where participants were required to complete tasks and provide feedback using different T-CSTs assessment forms. For example, researchers required participants to dance, paint, or build 3D models in a VR environment (Urban Davis et al., 2021; Lottridge et al., 2022) to evaluate external factors or engage in game-breaking with a social robot (Ali et al., 2021; Blanco et al., 2022).

Observation method was used in 32% studies, while questionnaires and data modeling were utilized in 30% experiments. Furthermore, 16% researchers analyzed user behavior data from device history and self-reports. One T-CSTs study used data mining and machine learning (Blanco et al., 2022), and two studies adopted physiological signal evaluations (Yang et al., 2018; Zhi et al., 2015).

The sample had a median of 16 participants and 25 in average. 56% of the experiments were designed for participants without a creative background, while 34% were for professionals, the rest involved both.

The evaluation standards could be divided into two categories: creativity-oriented and technology-oriented, which focus on measuring augmented human behaviors and technical performance, respectively. 31% studies were conducted using a variety of scales. The creativity-oriented standards adopted high-profile scale, like the *Test of Creative Thinking-Drawing Production (TCT-DP)* (Alves-Oliveira et al., 2020; Ali et al., 2021), the *Laban Movement Analysis (LMA)* (Yamaguchi and Kadone, 2017) and *Intrinsic Motivation Inventory (IMI)* (Baur et al., 2018). The technology-oriented standards generally used the *System Usability Scale (SUS)* (Cibrian et al., 2017; Costa et al., 2019; Guo et al., 2022) and *The National Aeronautics and Space Administration Task Load Index (NASA-TLX)* (Dube and Ince, 2019; Chen et al., 2021). Furthermore, a few scales combined both creativity and technology, such as the *Creativity Support Index (CSI)* (Fujinami et al., 2018).

We quantified their standards, as shown in Figure 6. *Expressivity*, *Originality*, *Novelty*, and *Surprise* of creative output were considered for creativity-oriented evaluation. Meanwhile, the *Accuracy* of artifacts used in idea expression was also mentioned. Furthermore, researchers concentrated on evaluating behavioral stimulations, which reflected the improvement of human attitudes toward artifacts, such as, *Engagement, Interest, User Experience, and Satisfaction*. There was also terms for technology evaluations, such as *Usability, Usefulness, Function*, etc.

Most of the researchers' hypotheses were validated, and their feedback was visualized in Figure 7. In technology-oriented evaluation, many studies valused the *Effectiveness of T-CSTs* (Yamaguchi and Kadone, 2017; Fujinami et al., 2018; Endow et al., 2022). Their findings for the creativity-centered evaluation include a *Change of mindset* (Ali et al., 2022; Matthews et al., 2022), *Higher interest* (Hubbard et al., 2021; Lottridge et al., 2022). Meanwhile, researchers also pointed out that technique understandability, the criteria of tasks, the selection of participants, and the adaptability of the actual scenario were essential for T-CSTs researches.

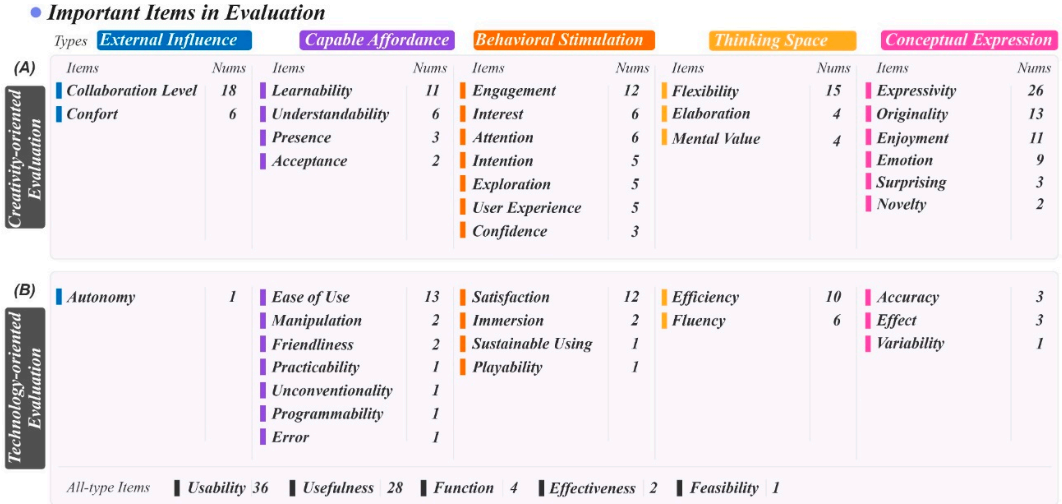

Figure 6. Important factors in T-CSTs evaluation: (A) creativity-oriented evaluation, (B) technology-oriented evaluation.

Figure 7. Users' performance using artifacts.

4. Discussion

The review result demonstrates the value of T-CSTs. First, the usage of T-CSTs improved user comprehension, engagement, and immersion. Second, T-CSTs integrated sensing devices into the development process, allowing expression through body movements and verbal interactions. Third, T-CSTs' afforded low-cost behavior patterns that benefits non-professional creators. Chapter 2.2 gave an overview of publications, including publishing tendencies and knowledge graph. The quantity of T-CSTs publications has grown in recent years.

It appears that much attention has been directed toward digitally disadvantaged groups, like children, rehabilitation groups. 33.7% of T-CSTs research focused on students to mine the exploratory epistemic inclusiveness of TUI, including enjoyment, playfulness, and esthetics of interaction. For example, the child-centered design space was afforded by embedding computation in physical environment (Elgarf et al., 2021; Blanco et al., 2022; Lahav and Wolfson, 2022). However, rehabilitation-related T-CSTs research received less attention and the elderly group did not appear in our sample.

From section 3. 2 Research Aims of T-CSTs, researchers raised questions focusing on effective co-creation, technological affordance, motivation arousal, content assistance, and augmented imagination. All these research questions involved technical, theoretical, and practical topics.

In section 3.3 Design Solutions, T-CSTs researchers combined design thinking and research methodologies to develop HCI tools to support creativity, e.g., cultivating critical thinking skills, reinforcing the effectiveness of ideas, and optimizing creative scaffolds, while creativity expression was less aimed at.

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T-CSTs researchers utilized emotion-related (e.g., Enjoyment, Surprising) as indicators of evaluation, but they are used as the design concepts of CST received limited attention. Hence, further exploration is necessary to determine whether and how these emotion-related and personality-related attributes can enhance creative performance in the design process potentially.

Section 3.4 Prototyping Technologies summarized how researchers implement TUI into design. Although most technologies actualized their hypotheses, some research still points out deficiencies in technical affordance (Jackson and Keefe, 2016), understandability (Strawhacker and Bers, 2015) and usability (Vishkaie, 2018) of manipulation.Although some studies have attempted to address the challenges of manipulation through the use of psychological interventions, this type of approach may not accurately reflect user adaptation to the technology. It is possible that biological channels was an under-appreciated but powerful solution. Recently, abundant biological models of creativity enabled us to capture the biological state of a user's intention and develop a more intelligent interaction system. However, almost all T-CSTs researchers have not yet utilized this. Although T-CSTs has a good technological paradigm to actualize creative application, improving the level of natural interaction is necessary to decrease the human cognitive load. Flexible technological paradigm should enable users to use them unobtrusively and operate at the periphery of their creative attention (Weiser and Brown, 1996).

Section 3.4 Evaluation of solutions described T-CSTs researchers' experimental methods, including participants, data collection, etc. Researchers selected quantitative, qualitative, and mixed evaluation methods based on their needs, such as long-term self-reporting and standard data collection in a laboratory setting. We recorded the evaluation items during data collection and found that both creativity and usability-oriented evaluation items were involved. The diversity of assessment approaches was an excellent advantage of T-CSTs but developing a standardized toolbox for a higher level of flexibility and rigidity in the evaluation was still essential.

T-CSTs showed a notable strength in diverse human-centered development and research solutions. Therefore, it is necessary to establish T-CSTs as a distinct discipline for greater attention. For theoretical application, a limited number of early research built on identifiable theoretical foundations for handling creativity-supported problems. Researchers used artifact designs to understand, test, and update creativity-supported theories. However, many studies formulated and approached the research question from a phenomenon-based and technological perspective, hindering the development of theoretical applications. Artifacts were construed as one-off exploratory prototypes in most T-CSTs cases without unified standards. Although many research have significant contributions, researchers did not extract or propose their theoretical benefits to construct systematic models for follow-up researchers.

5. Reflection & Opportunities

This chapter reflected on the research trends and proposed future opportunities to answer **research question 2**:

5.1. Emphasize the Research on Everyday Creativity Assistance

Professional creativity is not the only capacity that should be augmented by T-CSTs. Everyday creativity should also be considered, although it may not result in generating clear-cut, genius-level creative outputs in the short term (Merrotsy, 2013), i.e., humans' novel interpretation of experiences, actions, and events in the long-term cognitive activities (Kaufman and Beghetto, 2009). Everyday creativity has similarities with professional creativity and has the potential to evolve into professional creativity (Runco, 2014).

However, several papers researched on everyday creativity, i.e., *LoverBox* (Thieme et al., 2011), *AR-based face makeup system* (Treepong et al., 2018) and *T4Tags 2.0* (Bellucci et al., 2019). *T4Tags 2.0* allowed non-technical users to explore the smart home through easily triggered programs. *LoverBox* promoted the daily video-based co-creation to strengthen lovers' sense of belonging and intimacy. Nevertheless, T-CSTs are confronted with potential technical challenges :

- Hybrid materiality and interactive forms influence how interactivity is perceived by individuals, making affordance of TUI difficult to measure (Jung et al., 2017). However, using personalized intervention in TUI's component design can help users to build in-depth and controllable mental models during interaction. For example, by incorporating AI or generative components into hardware, e.g., the detection of users' creativity preferences, users can customize manipulation components and interaction forms to their cognitive processing, then facilitate long-term adoption of T-CSTs.
- T-CSTs could guide individuals to reflect on their self-directed and expression rather than providing excessive assistance. With reflection design, users can build a deeper understanding of creative space and give insight into the problems in everyday creation (Baumer et al., 2014).
- Evaluating the enhancement of everyday creativity by conducting experiments and workshops might be challenging to define augmented performance. Combining long-term and in-situ research approaches could capture the creators' variation of augmented indicators and avoid various biases, e.g., the novelty effect (Rutten et al., 2021).

5.2. Utilize the Inclusiveness of the Tangible User Interface for Patients

T-CSTs offer inclusive usage patterns for patients. Traditional rehabilitation technologies might have limitations regarding affordance, exploratory capabilities, and patient persistence. T-CSTs arouse patients' cognitive attributes, e.g., learn-by-doing, and improve their sensory skills, e.g., control sense of limbs, motivate patients to enhance their engagement in task-oriented therapy.

Our samples demonstrated TUI's applicability in improving patients' cognitive, sensory, and neuromuscular engagement in rehabilitation. First, the playfulness of T-CSTs offered embodied interactive feedback intuitively and enhanced the effectiveness of therapeutic intention (Seo et al., 2017; Cibrian et al., 2017; Neate et al., 2020; Alex et al., 2021). Second, T-CSTs with multi-sensory components, e.g., tactile manipulation, was utilized to bring comprehensive cognitive conditions in addressing patients' limited perceptual affordance (Cullen and Metatla, 2019; Sabuncuoglu et al., 2020; Somma et al., 2021). Third, in neuromuscular rehabilitation, TUI was applied to supply scientific, controllable, and regular limb training (Baur et al., 2018). These studies have shown T-CSTs' potential in rehabilitation. However, the current scenario of rehabilitation therapy might be limited and could be expanded.

- The concept of gamification can supply more engaging and satisfying experiences for users by arousing users' mental flow (Xiao et al., 2022). Based on gamification in component design, T-CSTs encourage patients to engage in physical activities to develop their collaboration, motor skills, and spatial cognition.
- T-CSTs could introduce therapy research through collaboration with professional rehabilitation scholars. Some effective therapies could be explored, such as *Cognitive Stimulation Therapy* for the elderly and caregivers (Fink, 2010; Pric and Tinker, 2014), *meditation* (Ding et al., 2014), *aerobic exercise* (Román et al., 2018) and *yoga* (Donnegan et al., 2018), *alpha/theta neurofeedback* for musical learners (Gruzelier, 2014).

5.3. Design Artifacts to Boost Creativity Expression

To improve the novelty and originality of creative outputs, T-CSTs could further stimulate users' profound creativity by enhancing users' emotions and personalities.

The literature did not show enough attention on augmenting creativity expression for emotional intervention. Emotion-supported research involved emotional arousal, reflection, and emotion presentation, which are embodied by vibrate feedback to stimulate inspiration (Giannoulis and Sas,

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2013), robot to train storytelling ability (Peng et al., 2020) and VR environment to train theatrical rehearsal (Bouville et al., 2016). There are research gaps in the accuracy of assessment methods, telematic usage scenarios, and individualized emotional mechanisms.

- Emotional assessment method in our sample tends to be single, relying on qualitative methods, such as self-report (Jang et al., 2019) and observation (Jones et al., 2020) and questionnaire (Peng et al., 2020). Researchers could improve the quality and accuracy of emotion caption with implicit and quantitative approaches (e.g., language, facial expressions, and galvanic skin response).
- It is worthwhile to explore emotional creativity in telematic usage scenarios. Some remote T-CSTs cases were distributed artifacts but did not concentrate on emotional creativity, like online sketching and idea-generation tools for remote meetings (Lee et al., 2017), telematic synchronous system for music learning (Thorn et al., 2021), motion-capture-based VR stage space for immersive dance (Lottridge et al., 2022). Researchers could conduct extensive emotion-related research for emotional scenarios in T-CSTs.
- There was no theoretical consensus regarding the relationship between emotion and creativity, such as viewpoints disputed in the positive and negative states (Lofy, 1998; Charyton et al., 2009), self-regulation from the properties of creative task (Zenasni and Lubart, 2002) and the activation level (De Dreu et al., 2008). Therefore, the individualized emotional mechanism of creativity needs to be further explored to elicit diversified emotional effects.
- Personality-supported cases use AI to amplify human personalities in design. T-CSTs researchers could further expedite the collaboration between humans and AI, allowing users to generate personality efficiently. For example, an AI-based multi-media environment could integrate users' personalities to build a more rhythmic, aesthetic, and immersive setting for better personalized expression.

5.4. Interact with Biological Data

Researchers could focus on the potential integration with biological mechanisms of creativity in informational input while using T-CSTs. Individual differences in creative performance are upon creativity-related psychological parameters, and neurobiological systems further determine these psychological features (Jauk, 2019). Multi-modal biological mechanisms of creativity relevant traits (e.g., imagination, emotion, motivation) improve humans' behavioral interpretability in creative performance (Martindale, 1999). For instance, the secretion of dopamine explains the improvement of creative motivation, which influences novelty-seeking and creativity-driven (Flaherty, 2005; DeYoung, 2013; Zaidel, 2014). Further, many imaging studies involved in detecting dopamine secretion and creative performance, e.g., using functional magnetic resonance imaging to capture creators' Aha!-moment to find insightful solutions (Tik et al., 2018). Therefore, with the biosensors or detection equipment, T-CSTs can understand humans' creative and decision-making intentions.

Here, three T-CSTs cases were collected involving biological modalities: *VibeRate* (Giannoulis and Sas, 2013) measured emotional arousal during inspiration-gathering phase using galvanic skin response sensors. One study used Electroencephalogram to control physical objects to improve mental concentration (Zhi et al., 2015). Eye-tracking system was also adopted (Guo et al., 2022). However, several points should be considered:

- First, most current biological mechanisms for creativity used emotion as predictive mediator, other traits did not receive much attention. Researchers could consider multiple factors for augmenting creativity to decrease the bias of bio-based prediction. Take attention as an example, researchers could take it as one of the predictors with others, e.g., emotion, motivation, and choose to correspond biological modal to actualize.

- Second, using a single biological modality to understand the creation process may not be precise enough. Multi-modal design techniques can free user's mental resources to reduce mental workload (Oviatt, 2006). A well-designed multi-modal system fusing two or more information sources can reduce recognition uncertainty (Oviatt, 2002). Multi-modal data facilitates the development of reliable and accurate recognition model for creativity.
- Researchers should promote the robustness of the devices and consider whether sensing devices might undermine the effects of creative expression. Some creative behaviors involve physical activities, such as dancing, performing, and brainstorming. For robustness, users' adaptivity, ongoing task, dialogue, environmental context, and input modes collectively generate constraints for the biological status detection.

5.5. Decrease Physical & Cognitive Load for Natural Interaction

To facilitate users' physical and mental engagement in the creative process, TUI could be used to reduce their cognitive and physical load in complex manipulation (Oviatt et al., 2006; Falcao et al., 2015). Therefore, further enhancing the operation affordance through interface design could decrease the human mental cognitive load. For example, with the help of heuristic creative conversation, users can execute creative tasks in a more mentally focused way (Kahn et al., 2014; Kahn et al., 2016). To diminish human physical load, T-CSTs reduced extraneous distractions while conducting creative tasks. For example, VR-based T-CSTs helped users to reach higher levels of self-confidence, flow status, and pleasant experience with less physical burden (Jackson et al., 2016; Yang et al., 2018; Costa et al., 2019).

Although users interacted with TUIs in relatively low-burden ways, long-term interaction may also cause physical exhaustion, like neck and spin (Dube et al., 2019). For example, AR display only can supply users with a limited collaborative space. The integration with GUI assistive devices in TUI-based tasks can reduce human error and improve decision-making by displaying real-time feedback. Thus, the relationship between the two types of interfaces should be further explored. In our samples, T-CSTs researchers applied GUI patterns such as tablets and projection in complex HRI tasks to give users visualized information to understand creativity-supported functions (Baur et al., 2018; Hu et al., 2021; Ali et al., 2022). We suggest GUI applications further improve visibility and streamline the creative process using focused interactive modules (icons and menus).

5.6. Balance and Standardize the Evaluation Process

Scientific research emphasizes the progress of knowledge, while design pursues the novel concepts and outcome. T-CSTs research as the combination of design and research, should balance the flexibility and rigidity in the evaluation procedures (Zimmerman and Forlizzi, 2014). So, using a mixed-methods approach, which incorporates both quantitative and qualitative measures, can improve the accuracy of evaluation. For example, Quantitative data such as task completion time and user satisfaction can provide a direct understanding of the T-CSTs' performance, while qualitative measures such as interviews and observations can provide a more subjective and nuanced understanding of the tool's impact. Qualitative measures can also help to identify external factors that affects user satisfaction.

It is necessary to develop a systematic toolbox to evaluate T-CSTs to improve the standardization of the evaluation procedure. Standardized evaluation is critical for improving effectiveness, evidence-based development, user-centered design, and research advancement. Furthermore, it enables the gathering of empirical evidence to indicate future directions and compare different tools and approaches.

6. Limitation

All the research opportunities we proposed to stem from the inductive trend we extracted from existing T-CSTs papers, yet this scoping review had several limitations. Firstly, our selection and inclusion process may have bias and cannot fully represent trends and opportunities in the T-CSTs field due to the varying perspectives and preferences of different scholars and the potential limitations of the search strategy employed. Secondly, given the nascent stage of research in this area, as evidenced by the quality of the articles reviewed, the identification of trends and opportunities should be viewed with some caution, as these are likely to evolve as the field matures. Lastly, this review focuses primarily on studies published in English, which may have resulted in the exclusion of relevant research published in other languages.

7. Conclusions

This scoping review showed a first-time attempt to induct the current trend and critically discussed future opportunities of T-CSTs. We extract the research trend based on 86 publications by analyzing their research process of research question generation, artifact design, technological application, and evaluation.

Drawing on our key findings and critical reflection, we identify several opportunities to solve current research gaps, shown below: (1) Further research is needed to fully explore the potential of T-CSTs in facilitating everyday creativity, concentrating on developing in-depth mental models, reflective design, and longitudinal evaluations. (2) T-CSTs offer more inclusive concepts for constructing interaction forms that should be expanded further, with consideration for higher gamification and broader scenarios. (3) More attention should be given to augmenting expressive creativity by improving humans' emotional states. Researchers should address research gaps related to the accuracy of assessment methods, telematic usage scenarios, and individualized emotional mechanisms. (4) To improve T-CST's effectiveness in identifying human creative intention, researchers could focus on the diverse predictive bio-mediators, multi-modal data sources, and usage stability of T-CSTs. (5) Natural interaction still faces ergonomic challenges of physical load. Researchers may consider the implementation of assistive GUI devices. (6) To improve the effectiveness of results, researchers can develop mixed methods and standardized toolboxes.

In design practice, we structured the development process of T-CSTs prototypes systematically, offering a clear guide for industry professionals. Then, we explored T-CSTs' potential applications and innovative significance in various domains. With this research, industry professionals can gain a better understanding of T-CSTs technology and apply it to a variety of practical scenarios. Last, this review provided a comprehensive analysis and explanation of the key issues in T-CSTs, facilitating a better understanding of the trends and opportunities in this field.

Appendix

Screening Samples of Review

Table A1. Screening samples of this review.

Authors and Times	*Entry Point(s)*	*Augmented Factor(s)*	*Application*	*Name of Artifacts*	*Technological Actualization*	*Design Purposes*	*Contribution type*	*Used Scale & Standard*
(Lottridge et al., 2022)	Integration;Expression	Situation;Emotion;Driven Force	Art	BeatSaber (Demo), OhShape, Tilt Brush	VR Applications with Matching handle	Reinforcement of user experience	Qualitative study	Subjective definition
(El-Zanfaly et al., 2022)	Integration;	Cooperation;	BusinessInnovation	Sand Playground	Tabletop Systems with a Projection system	Formation and implementation of collaboration	Qualitative study	Subjective definition
(Ali et al., 2022)	Integration;Execution	Cooperation; Mindset;Rhythm	Education	Escape!Bot	Social Robots with GUI Application	Formation of mindset	Mixed-Method study	Subjective definition
(Guo et al., 2022)	Availability;	Ability;	BusinessInnovation	VibeRate	Productivity tools	Optimization of threshold and skill	Quantitative study	SUS
(Senaratne et al., 2022)	Availability;	Knowledge;	Rehabilitation	TronicBoards	IoT Toolkits	Optimization of threshold and skill	Qualitative study	Subjective definition
(Blanco et al., 2022)	Integration;	Cooperation;	Education	Nikivision	IoT Toolkits with a Projection system	Formation and implementation of collaboration	Quantitative study	Educational data mining (EDM)
(Matthews et al., 2022)	Integration;Execution	Cooperation; Mindset;	Education	Animettes	IoT Toolkits	Formation and implementation of collaboration	Qualitative study	Subjective definition
(Endow et al., 2022)	Availability;	Ability;	Art	Embr LCTD	IoT Toolkits	Ideal manifestation	Quantitative study	Subjective definition
(Li et al., 2022)	Integration;Availability	Cooperation; Ability;Mindset	Education	stayFOCUSed, Group Hexagon, Tower, Remolight, Glowing Wand	IoT Toolkits	Ideal manifestation	Mixed-Method study	User experience
(Lahav et al., 2022)	Availability;	Ability;	Education	Osmo Tangram	IoT Kits with GUI Application	Improvement of intelligence	Quantitative study	Subjective definition
(Thorn, 2021)	Implementation;	Motivation;	Education	Unnamed	Wearable products with GUI Application	Ideal manifestation	Quantitative study	Subjective definition
(Urban Davis et al., 2021)	Integration;Expression	Cooperation; Situation;Personality	BusinessInnovation	Calliope 3D modeling	VR Applications	Formation and implementation of collaboration	Qualitative study	Subjective definition
(Alex et al., 2021)	Implementation;Integration	Motivation;Situation;	Rehabilitation	Unnamed	VR Applications	Reinforcement of user experience	Qualitative study	Subjective definition

doi:10.20944/preprints202407.2615.v1

(Ali et al., 2021)	Integration;	Cooperation; Situation;	Education	Jibo	Social Robots with GUI Application	Ideal manifestation	Mixed-Method study	TCT-DP
(Hubbard et al., 2021)	Execution;Implementation	Mindset;Rhythm;Driven Force	Entertainment	DIY Fluffy Robots	Social Robots with GUI Application	Improvement of cognition and knowledge	Mixed-Method study	Affinity diagramming and thematic analysis
(Hu et al., 2021)	Integration;	Cooperation; Situation;	Art	Kuri	Social Robots with a Projection system	Ideal manifestation	Mixed-Method study	Factors of Divergent Thinking
(Elgarf et al., 2021)	Integration;Execution	Cooperation; Situation;Rhythm	Entertainment	CUBUS and NAO robot	Social Robots with GUI Application	Formation of mindset	Quantitative study	Subjective definition
(Ali et al., 2021)	Integration;Execution	Cooperation; Situation;Mindset	Entertainment	Jibo	Social Robots with GUI Application	Formation of mindset	Mixed-Method study	TTCT, TCT-DP
(Belakova and Mackay, 2021)	Integration;Implementation	Situation;Driven Force;	Work	SonAmi	Productivity tools with Cup	Ideal manifestation	Qualitative study	Subjective definition
(Somma et al., 2021)	Availability;Execution	Ability;Mindset;Driven Force	Rehabilitation	Unnamed	IoT Toolkits with GUI Application	Improvement of cognition and knowledge	Mixed-Method study	Subjective definition
(Chen et al., 2021)	Availability;	Ability;Knowledge;	Education	FritzBot	IoT Toolkits	Optimization of threshold and skill	Quantitative study	USE, NASA-TLX
(Hirsch et al., 2021)	Availability;Implementation	Knowledge; Motivation;	Art	Unnamed	IoT Products	Improvement of cognition and knowledge	Quantitative study	Subjective definition
(Tseng et al., 2021)	Implementation;Availability	Motivation;Ability;Emotion	Entertainment	PlushPal	IoT Kits with GUI Application	Ideal manifestation	Mixed-Method study	Subjective definition
(Martelloni et al., 2021)	Availability;Implementation	Ability;Driven Force;	Art	Unnamed	Instruments	Reinforcement of user experience	Qualitative study	Subjective definition
(Im and Rogers, 2021)	Expression;Implementation	Emotion;Motivation;	Education	Draw2Code	AR Applications with GUI Application	Improvement of cognition and knowledge	Qualitative study	Subjective definition
(Jones et al., 2020)	Implementation;	Motivation;	BusinessInnovation	Wearable Bits	Wearable products	Optimization of threshold and skill	Qualitative study	Subjective definition
(Segura et al., 2020)	Implementation;Integration	Motivation;Situation;	Education	VR-OCLS	VR Applications with Matching handle	Promotion of environment and situation	Qualitative study	Subjective definition
(Neate et al., 2020)	Availability;	Knowledge;Ability;	Rehabilitation	CreaTable	Tabletop Systems with GUI Application	Optimization of threshold and skill	Qualitative study	Subjective definition
(Kim, 2020)	Execution;Implementation	Mindset;Driven Force;	Education	EPL-based robot	Social Robots	Formation of mindset	Quantitative study	Subjective definition

doi:10.20944/preprints202407.2615.v1

(Alves-Oliveira et al., 2020)	Execution;Implementation	Mindset;Motivation;Driven Force	Education	YOLO	Social Robots	Formation of mindset	Quantitative study	TCT-DP, CREA
(Peng et al., 2020)	Expression;Execution	Emotion;Mindset;	Education	Unnamed	Social Robots	Emotional awakening	Quantitative study	Subjective definition
(Lin et al., 2020)	Integration;Implementation	Cooperation; Motivation;	BusinessInnovation	Cobbie	Social Robots	Reinforcement of user experience	Mixed-Method study	CSI
(Sabuncuoglu, 2020)	Availability;Integration	Ability;Situation;	Rehabilitation	Unnamed	IoT Toolkits	Optimization of threshold and skill	Qualitative study	Subjective definition
(Cox and Semwal, 2020)	Integration;	Situation;	Art	Line-Storm Ludic System	IoT Toolkits with GUI Application	Promotion of environment and situation	Qualitative study	Subjective definition
(Jessen et al., 2020)	Availability;	Ability;	BusinessInnovation	Unnamed	AR Applications	Ideal manifestation	Quantitative study	Objective definition
(Le Goc et al., 2020)	Integration;	Cooperation;	Entertainment	Zooid	AR Applications with Lego Mindstorms	Formation and implementation of collaboration	Qualitative study	Subjective definition
(Costa et al., 2019)	Integration;	Situation;	Art	Songverse	VR Applications with Matching handle	Reinforcement of user experience	Mixed-Method study	SUS
(Rond et al., 2019)	Integration;	Situation;	Art	ImprovBot	Social Robots	Ideal manifestation	Qualitative study	Subjective definition
(Jang et al., 2019)	Implementation;	Motivation;Driven Force;	Work	Monomizo	Productivity tools	Reinforcement of user experience	Qualitative study	Subjective definition
(Aslan et al., 2019)	Availability;Integration	Ability;Situation;	Work	Unnamed	Productivity tools with GUI Application	Reinforcement of user experience	Quantitative study	Subjective definition
(Bellucci et al., 2019)	Availability;	Ability;	Life	T4Tags 2.0	Life and home supple	Ideal manifestation	Mixed-Method study	Subjective definition
(Tamashiro et al., 2019)	Implementation;	Motivation;	Education	Unnamed	IoT Toolkits	Ideal manifestation	Qualitative study	Subjective definition
(Chou et al., 2019)	Implementation;Execution	Motivation;Driven Force;Mindset	Education	e-Tuning	IoT Toolkits with GUI Application	Optimization of threshold and skill	Quantitative study	Subjective definition
(Masril et al., 2019)	Availability;Execution	Ability;Mindset;	Entertainment	Lego Mindstorms	IoT Toolkits	Formation of mindset	Quantitative study	TKF
(Cullen and Metatla, 2019)	Availability;Implementation	Ability;Motivation;	Rehabilitation	Unnamed	IoT Kits	Formation of mindset	Qualitative study	Subjective definition
(Chen et al., 2019)	Expression;	Emotion;	Entertainment	Humming box	IoT Kits	Formation of mindset	Qualitative study	Subjective definition
(Scheidt and Pulver, 2019)	Availability;	Ability;	Education	Any-Cubes	IoT Kits	Improvement of cognition and knowledge	Qualitative study	Subjective definition

doi:10.20944/preprints202407.2615.v1

(Law et al., 2019)	Integration;	Situation;	BusinessInnovation	Nameless HRCD system	Interactive Systems with GUI Application	Management of workspace	Mixed-Method study	Subjective definition
(Dube and ince, 2019)	Integration;	Situation;	Art	Nameless device	AR Applications with GUI Application	Reinforcement of user experience	Quantitative study	Think-aloud approach, User Interaction Satisfaction (QUIS), the Computer Usability Satisfaction Questionnaire, NASA Task Load Index (NASA TLX)
(Sarkar et al.,2019)	Integration;Execution	Cooperation; Mindset;	Education	Unnamed	AR Applications with GUI Application	Formation and implementation of collaboration	Mixed-Method study	Guilford's test of divergent thinking
(Men and Bryan-Kinns, 2018)	Availability;Integration	Ability;Situation;	Art	LeMo	VR Applications with Matching handle	Management of workspace	Qualitative study	Subjective definition
(Eteokleous et al., 2018)	Availability;Execution	Knowledge; Mindset;	Education	Multi-prototype	Social Robots	Formation of mindset	Quantitative study	TTCT
(Yang et al., 2018)	Integration;	Situation;	BusinessInnovation	Unnamed	VR Applications with Matching handle	Ideal manifestation	Quantitative study	K-DOCS, EEG
(Fujinami et al., 2018)	Execution;	Mindset;	Art	UnicrePaint	Tabletop Systems with GUI Application	Ideal manifestation	Mixed-Method study	CSI
(Baur et al., 2018)	Availability;	Ability;	Rehabilitation	ARMin+musical environment	Social Robots with GUI Application	Ideal manifestation	Quantitative study	IMI
(Ehrenberg et al., 2018)	Integration;	Situation;	Work	SENSE-SEAT	Productivity tools	Promotion of environment and situation	Qualitative study	Subjective definition
(Mäkelä and Vellonen, 2018)	Availability;	Ability;Knowledge;	Education	Makey Makey	IoT Toolkits	Optimization of threshold and skill	Qualitative study	Subjective definition
(Treepong et al., 2018)	Availability;	Ability;	Life	Unnamed	AR Applications with GUI Application	Ideal manifestation	Quantitative study	Subjective definition
(Vishkaie, 2018)	Implementation;	Motivation;	Education	Unnamed	AR Applications with Wearable product	Reinforcement of user experience	Qualitative study	Subjective definition
(Nguyen et al., 2017)	Integration;	Situation;	Work	Vremire	VR Applications with GUI Application	Promotion of environment and situation	Qualitative study	SSQ

doi:10.20944/preprints202407.2615.v1

(Kountouras and Zannos, 2017)	Integration;Implementation	Cooperation; Motivation;	Education	GESTUS	Tabletop Systems	Formation and implementation of collaboration	Mixed-Method study	Subjective definition
(Lee et al., 2017)	Integration;	Cooperation;	Work	All4One	Tabletop Systems with the Projection system	Ideal manifestation	Qualitative study	Subjective definition
(Yamaguchi and Kadone, 2017)	Expression;Availability	Emotion;Ability;	Education	TwinkleBall	IoT Products with GUI Application	Optimization of threshold and skill	Quantitative study	LMA
(Seo et al., 2017)	Execution;	Mindset;	Rehabilitation	Unnamed	IoT Kits	Formation of mindset	Qualitative study	Subjective definition
(Cibrian et al., 2017)	Availability;	Ability;	Rehabilitation	BendableSound	Interactive Systems	Optimization of threshold and skill	Mixed-Method study	SUS
(Bouville et al., 2016)	Integration;	Situation;	Art	Unnamed	VR Applications	Promotion of environment and situation	Qualitative study	Subjective definition
(Jackson et al., 2016)	Integration;	Situation;	Art	Lift-Off	VR Applications with Intelligent pen	Ideal manifestation	Mixed-Method study	Subjective definition
(Kahn et al., 2016)	Execution;Availability	Mindset;Ability;	Education	ATR's Robovie	Social Robots with Sand table	Formation of mindset	Mixed-Method study	Subjective definition
(Tintarev et al., 2016	Availability;	Ability;Knowledge;	Education	Unnamed	IoT Toolkits	Optimization of threshold and skill	Qualitative study	Subjective definition
(Zhi et al., 2015	Implementation;	Motivation;Driven Force;	Education	Unnamed	Social Robots with Lego Mindstorms	Ideal manifestation	Quantitative study	EEG
(Strawhacker and Bers, 2015)	Integration;Execution	Situation;Mindset;	Education	LEGO WeDo	IoT Toolkits with GUI Application	Promotion of environment and situation	Mixed-Method study	Solve Its
(Jou and Wang, 2015)	Execution;	Mindset;	Education	Unnamed	Interactive Systems	Formation of mindset	Quantitative study	CCTST, PAC
(Kahn et al., 2014)	Integration;Availability	Situation;Ability;	BusinessInnovation	ATR's Robovie	Social Robots with GUI Application	Ideal manifestation	Qualitative study	Subjective definition
(Cosentino et al., 2014	Integration;	Situation;	Art	WB-4 robot system	Social Robots	Ideal manifestation	Quantitative study	Subjective definition
(Wang et al., 2014)	Execution;	Mindset;	Education	StoryCube	IoT Kits with GUI Application	Formation of mindset	Qualitative study	Subjective definition
(Branje and Fels, 2014)	Availability;	Ability;Knowledge;	Art	Vibrochord	Instruments	Ideal manifestation	Quantitative study	Instrument characteristics
(Salvador-Herranz et al., 2014)	Integration;	Cooperation;	Work	Unnamed	AR Applications with a Projection system	Formation and implementation of collaboration	Qualitative study	Subjective definition
(Campos et al., 2014)	Execution;	Mindset;	Work	Second Look	AR Applications	Ideal manifestation	Qualitative study	Subjective definition
(Yamaoka and Kakehi, 2013)	Integration;	Situation;	Work	DePENd	Productivity tools with GUI Application	Promotion of environment and situation	Mixed-Method study	Subjective definition

doi:10.20944/preprints202407.2615.v1

(Nasman and Cutler, 2013)	Availability;	Ability;Knowledge;	BusinessInnovation	Unnamed	Interactive Systems with a Projection system	Optimization of threshold and skill	Mixed-Method study	Subjective definition
(Barbosa et al., 2013)	Availability;Implementation	Ability;Driven Force;	Art	Illusio	Instruments	Reinforcement of user experience	Qualitative study	Subjective definition
(Giannoulis and Sas, 2013)	Expression	Emotion	BusinessInnovation	VibeRate	Wearable	Ideal manifestation	Quantitative study	Subjective definition
(Schmitt et al., 2012)	Integration;	Cooperation;	Work	Unnamed	Tabletop Systems with a Projection system	Ideal manifestation	Qualitative study	Subjective definition
(Liu et al., 2012)	Expression;Availability	Emotion;Ability;	Education	Unnamed	IoT Products with GUI Applications	Optimization of threshold and skill	Quantitative study	LMA
(Thieme et al., 2011)	Implementation;Expression	Motivation;Driven Force;Emotion	life	Lovers' box	Life and home supple	Optimization of threshold and skill	Qualitative study	Subjective definition

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