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Evaluating an Integrated Computational Thinking and Design Thinking Module to Foster Co-Creation Among Primary School Students: An Empirical Study Using the Kirkpatrick Framework

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Abstract: *This study explores the feasibility and pedagogical value of an integrated Computational Thinking–Design Thinking (CT–DT) module designed to foster co-creation by promoting essential 21st-century competencies—creativity, critical thinking, collaboration, and communication (4Cs)—among primary school students. Grounded in constructionist learning theory (Papert, 1980) and the knowledge co-creation framework (Bereiter & Scardamalia, 2006), the intervention was implemented in a project-based learning (PjBL) environment involving 35 Year 3 pupils in China. The module combined algorithmic reasoning (e.g., abstraction, decomposition, and iteration) with human-centred design processes (e.g., empathy, ideation, prototyping). The New World Kirkpatrick Model was used to evaluate student engagement and learning outcomes (Levels 1 and 2). Qualitative data from classroom observations revealed rich interpersonal collaboration and communicative practices, while quantitative results showed statistically significant improvements in creativity and critical thinking ($p < .001$, large effect sizes). These findings provide empirical support for the integration of CT–DT approaches in interdisciplinary primary education to cultivate co-creation competencies in authentic learning environments.*

Keywords: Computational thinking, Design thinking, Collaborative learning, Elementary education, 21st century skills

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1. Introduction

Over the past decade, Computational Thinking (CT) and Design Thinking (DT) have gained increasing prominence as foundational competencies in 21st-century education (Crilly, 2024; Kelly & Gero, 2021). Numerous studies highlight their potential to foster the "4Cs"—critical thinking, creativity, collaboration, and communication—particularly in primary-level learning environments (Carroll, 2015; Cook & Bush, 2018; Tan et al., 2024; Thornhill-Miller et al., 2023; Wong & Cheung, 2020). When combined, CT and DT form a complementary pedagogical framework that merges algorithmic reasoning with human-centered innovation, equipping learners to navigate complex, ill-structured ("wicked") problems (Buchanan, 1992; Sengupta et al., 2013; Fayanto et al., 2024). At the same time, co-creation has emerged as a critical construct in educational theory, emphasizing learners' active agency in generating knowledge, shaping inquiry, and co-producing meaningful outcomes (Bereiter & Scardamalia, 2006, 2010; Cook-Sather & Matthews, 2021). Rather than viewing students as passive recipients, co-creation reframes them as epistemic agents engaged in authentic, collaborative learning. This perspective aligns closely with the 4Cs, which are increasingly regarded as essential competencies for fostering deeper engagement and future readiness (Dede, 2010; Voogt & Roblin, 2012; Thornhill-Miller et al., 2023). Despite growing conceptual interest, co-creation remains underexplored in empirical studies, particularly those involving integrated CT–DT interventions in primary STEM education.

Nevertheless, empirical investigations continue to lack systematic, methodologically rigorous evaluations of CT–DT implementation, particularly within authentic STEM education contexts in China. Specifically, most studies focus on application in secondary or higher education, often overlooking authentic learning environments' complexity and interdisciplinary nature (Li & Zhan, 2022; Li et al., 2021). Furthermore, many interventions have been criticized for their limited authenticity and contextual relevance, often relying on decontextualized tasks such as puzzle-based coding or superficial design activities that often lack contextual authenticity and interdisciplinary relevance (Almerich et al., 2016; Angeli & Valanides, 2020; Li & Zhan, 2022; Wang & Wang, 2024).

To bridge the gap between theoretical propositions and empirical implementation, this study offers empirical support for the integration of technology-enhanced, interdisciplinary CT–DT modules that embed learning within authentic STEM contexts and foster transferable co-creative problem-solving skills. A growing body of evidence identifies project-based learning (PjBL) as an effective approach to promote meaningful learner engagement in interdisciplinary problem-solving, enabling students to apply CT and DT while engaging with complex, real-world problems. Recent studies further demonstrate how these models leverage emerging digital tools—such as visual programming platforms, AI-supported design environments, and IoT-enabled systems—to strengthen learner engagement and promote cross-domain problem-solving competencies (Fayanto et al., 2024; Kim et al., 2023; Lai, 2023).

Effective CT–DT integration depends on collaborative problem-solving environments. This study draws on principles from constructivist learning theory and design-based learning models, both of which emphasize learner agency, contextual engagement, and the co-construction of knowledge (Ning, 2025; Fayanto et al., 2024; Rahman et al., 2023; Wang & Wang, 2024). Recent studies consistently report that collaborative environments facilitate deeper learner engagement with complex tasks in ways that deepen understanding and foster transferable skills. In particular, Li and Zhan's (2022) systematic review identifies task authenticity as a critical factor shaping the success of DT–CT integration. Their analysis corroborates that when learning activities are situated in real-world contexts, students are more likely to experience increased motivation, exercise critical thinking, and demonstrate improved transfer of learning across domains. This perspective is supported by several recent empirical studies, which consistently highlight the pedagogical value of authentic, interdisciplinary tasks in enhancing both cognitive and affective learning outcomes (Kim et al., 2023; Lai, 2023; Wang & Wang, 2024). These findings highlight the need to situate DT–CT modules in learning environments that mirror the complexity of real-world problems.

1.1 Purpose and significance of this study

This study aims to evaluate an integrated Computational Thinking–Design Thinking (CT–DT) module for enhancing co-creation in primary school students. Specifically, the 4Cs are used as evaluative dimensions to examine how and whether the CT–DT module fosters co-creation among learners. The module includes structured learning activities that combine computational processes (e.g., decomposition, abstraction, algorithmic thinking) with human-centred design practices (e.g., empathy, ideation, prototyping).

This study contributes to the field by addressing the paucity of empirical investigations into CT–DT integration within primary education contexts. Although theoretical support for integrating CT and DT is growing, empirical implementation—particularly in primary settings—remains limited. To address this gap, the New World Kirkpatrick Model (NWKM) was employed to assess both reaction-level and learning-level outcomes, thus providing a structured approach to empirical evaluation.

This study addresses two principal research questions as follows:
RQ1: How is the feasibility of the CT–DT module demonstrated through communication and collaboration among primary school pupils, based on Level 1 (Reaction) of the New World Kirkpatrick Evaluation Model?
RQ2: What is the effect of the CT–DT module on fostering critical thinking and creativity among primary school pupils, as assessed through Level 2 (Learning) indicators of the New World Kirkpatrick Evaluation Model?

To test the usability of the intervention, hypotheses were formulated for RQ2 as follows:
H_0: There is no significant difference in students' creativity and critical thinking scores before and after the CT–DT module intervention.
H_1: There is a significant improvement in students' creativity and critical thinking scores after the CT–DT module intervention.

In summary, given the essential role of engagement in CT–DT integration for fostering 4C competencies, there is a growing imperative to investigate implementation in practice. A systematic examination of students' engagement and cognitive skill development within a CT-DT-based learning module is critical for informing the design of learning environments that are developmentally appropriate and learner-responsive. By evaluating behavioural engagement and performance in key 21st-century skills, the research contributes meaningfully to the theoretical discourse on co-creation in education. The findings inform the iterative refinement of CT–DT instructional design within interdisciplinary, project-based learning environments.

2. Related Work

2.1 Theoretical framework

This study is grounded in constructivist learning theory, as illustrated in Error! Reference source not found.， drawing upon the learning theory foundations of constructionism (Papert, 1980) and knowledge co-creation (Bereiter, 1985). The foundational theoretical framework integrates cognitive constructivism (Piaget, 1970) and social constructivism (Vygotsky, 1978). More specifically, this study adopts a dual-layered conceptual and analytical framework. Theoretically, it is grounded in constructionist and social constructivist perspectives (Papert, 1980; Vygotsky, 1978), which position learners as active knowledge constructors within collaborative environments. Analytically, the study operationalizes the abstract concept of "co-creation" through the 4Cs framework—creativity, critical thinking, communication, and collaboration—drawing from established 21st-century learning competencies (Voogt & Roblin, 2012; Trilling & Fadel, 2009). These four constructs serve as pedagogical principles and measurable behavioral dimensions that enable a structured evaluation of learner engagement and cognitive development during CT–DT integration. This integrated framework highlights the significance of active learner participation, the co-construction of meaning through social interaction, and the development of tangible artefacts within authentic learning contexts. This study evaluates the application of CT–DT modules in a PjBL environment to promote co-creation among students.

CT and DT are increasingly conceptualised as foundational competencies for problem-solving, particularly education. Numerous scholars have acknowledged the increasing relevance of both CT and DT as critical competencies for learners navigating a rapidly changing, complex world (Kelly & Gero, 2021; Sherwood et al., 2021). For example, Kelly and Gero (2021) propose a dual-process perspective, suggesting that CT and DT function as complementary and interdependent modes of cognition. CT emphasizes logical reasoning, abstract modelling, and algorithmic thinking, while DT focuses on human-centered exploration, iterative optimization, and creativity (Razzouk & Shute, 2012; Wing, 2006).

Accordingly, the primary objective of integrating CT and DT into STEM settings is to cultivate co-creation as a means to address wicked problems. This process is particularly important for fostering the 4C competencies in students.This integration is particularly relevant in primary education. Primary school students transition from concrete manipulation to abstract reasoning (Papert, 1980). Integrating CT and DT offers a bridge between hands-on experience and cognitive development. Research in cognitive development suggests that scaffolding abstract thinking through concrete, collaborative tasks supports deeper conceptual engagement and facilitates the development of higher-order understanding (Sherwood et al., 2021). Specifically, CT contributes to developing systematic reasoning through problem decomposition, abstraction, and algorithmic thinking. By contrast, DT supports iterative design, empathy, and tangible prototyping, thus catering to early learners' need for experiential and embodied engagement (Razzouk & Shute, 2012;Luka, 2014).

Thus, the CT and DT module application in primary education serves not only to foster creative and analytical competencies but also to equip learners with the adaptive skills needed to tackle real-world, ill-structured problems. By engaging students in both algorithmic reasoning and empathetic design, such integration aims to develop flexible, transdisciplinary problem-solving skills suited for 21st-century challenges (Nordby et al., 2024; Yeung & Ng, 2024).

In summary, the integration of CT and DT offers a promising approach to fostering 21st-century competencies, although its application at the primary level remains underexamined. However, effective implementation depends on participatory approaches—particularly co-design and co-creation—that actively engage stakeholders (e.g., educators and students) in collaboratively shaping learning experiences that are both contextually relevant and cognitively appropriate (Bonani et al., 2022; Yadav & Berthelsen, 2021). These collaborative models ensure that integrated CT-DT curricula respond to theoretical ideals and the lived realities of young learners and their educators. The present study adopts the NWKM (Kirkpatrick & Kirkpatrick, 2016) as the sole framework for evaluating feasibility and usability of the CT–DT instructional module. The NWKM outlines four hierarchical levels of evaluation: Reaction, Learning, Behaviour, and Results. However, considering the study’s scope and educational context, the present evaluation is confined to the first two levels, namely, Reaction and Learning.

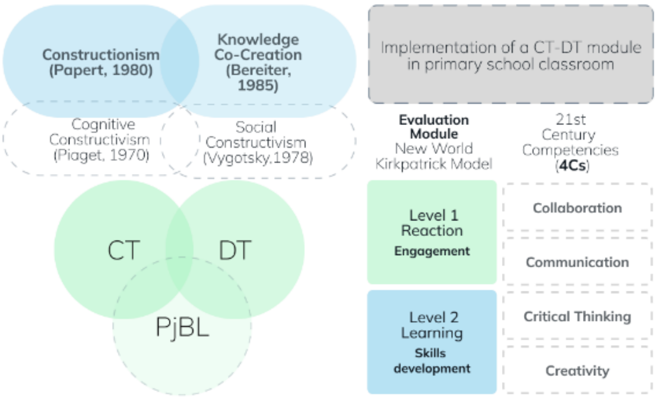


Figure 1: Theoretical framework: Conceptual and Analytical Framework for Evaluating Co-Creation through CT–DT Integration.

Note. The left panel illustrates the theoretical foundation rooted in constructionist and social constructivist learning theories, emphasizing learner agency, collaborative meaning-making, and artefact creation. The 4Cs—creativity, critical thinking, communication, and collaboration—are presented as operational constructs that translate co-creation into measurable behavioral and cognitive outcomes. The right panel maps these outcomes onto Levels 1 and 2 of the New World Kirkpatrick Model, enabling structured analysis of both engagement (reaction level) and skill development (learning level) within the CT–DT project-based learning context.

Figure 1 illustrates the study's integrated conceptual and analytical framework. The left panel visualizes the theoretical grounding in constructionism and knowledge co-creation, highlighting learner agency, social interaction, and artefact creation. The 4Cs (creativity, critical thinking, communication, collaboration) function as bridging constructs between theory and practice—providing observable dimensions of co-creation within classroom activity.

The right panel of **Error! Reference source not found.** shows the alignment with the New World Kirkpatrick Model (Levels 1 and 2), which structures the evaluation into two tiers: behavioral engagement (communication, collaboration) and cognitive development (critical thinking, creativity). This design supports a systematic analysis of how CT–DT instruction fosters measurable co-creative learning outcomes in primary education.

1.2.1 Evaluation of Reaction

This level is conducted immediately after the instructional experience and focuses on students' communicative and collaborative behaviours. Classroom observation is the principal method for capturing learners' affective responses and engagement (Rodriguez et al., 2015; Blikstein & Worsley, 2016). The observational data are systematically analysed to determine how the module fosters active participation and supports interpersonal interaction, consistenting with the social dimensions of constructivist learning. Data were thematically analysed to assess the extent to which the CT–DT module fostered active participation, peer dialogue, and interpersonal coordination. This evaluation does not examine individual satisfaction or perceptions, but rather centres on observable indicators of social interaction, consistent with constructivist learning principles (Vygotsky, 1978; Hattie & Anderman, 2013). This reaction-level evaluation focuses on two key dimensions, as outlined below:

Dimension 1: communication

Dimension 2: collaboration

1.2.2 Evaluation of Learning

This level examines how students have acquired the targeted knowledge and skills, particularly critical thinking and creativity. A structured pre–post questionnaire was administered before and after the intervention to ensure objectivity and facilitate quantifiable measurement. This design identifies measurable changes in individual student performance, allowing for statistical analysis of learning outcomes attributable to the CT–DT module. Consistent with educational research practices that propose for evidence-based assessment of cognitive development (Sáez-López et al., 2016; Angeli & Valanides, 2020), descriptive and inferential statistical analyses were conducted to evaluate shifts in students' cognitive competencies and infer the module's effectiveness in promoting learning. This learning-level evaluation focuses on two key dimensions, as outlined below:

Dimension 3: critical thinking
Dimension 4: creativity

Specifically, the learning evaluation targeted adaptive decision-making in co-creation tasks, operationalised through cognitive dimensions such as reasoning, ideation, and iterative problem-solving. These competencies are essential for navigating ill-structured, interdisciplinary problems and are consistently emphasised in 21st-century learning frameworks (Kelly & Gero, 2021; Harwood et al., 2024; Yeung & Ng, 2024). Therefore, the CT–DT module was designed to foster both individual and collaborative cognitive competencies in authentic, project-based learning environments.

Although prior research has examined CT and DT independently within K–12 educational contexts (Bers, 2018; Lin et al., 2020), few studies have investigated their integrated application, particularly in primary-level collaborative learning environments. Moreover, empirical studies evaluating the combined impact of CT and DT on the development of the 4Cs remain limited. This study contributes to addressing this gap by evaluating an integrated CT–DT module through behavioural and cognitive indicators of co-creation within an authentic PjBL context.

2.2 Computational Thinking

The definition of computational thinking (CT) remains ambiguous and contested, encompassing a range of overlapping concepts without a unified discourse (Lye & Koh, 2014). Unlike technical computer-use skills or encouraging individuals to adopt machine-like reasoning, CT emphasizes the thinking modes of computer scientists or how humans solve problems (Wing, 2006). From the lens of cognitive development, two major conceptualisations of CT have emerged in the literature, namely, (1) approaches that highlight the thinking processes of computer scientists (Brennan & Resnick, 2012; Denner et al., 2012; Weintrop et al., 2016; Wing, 2006); and (2) those that focus on domain knowledge and general problem-solving skills (Cheng et al., 2023; Grover& Pea, 2013;; ISTE & CSTA, 2011; Palop et al., 2025; Selby & Woollard, 2013; Yadav et al., 2016). ISTE and CSTA proposed an operational definition in 2011, outlining core competencies—like abstraction, data analysis, and algorithmic thinking—and key dispositions such as perseverance and collaboration. Embedded in ISTE and CSTA standards, the framework has guided interdisciplinary CT integration and shown positive impacts on student engagement and STEM performance (ISTE & CSTA, 2011; ISTE, 2020; Grover & Pea, 2013; Cheng et al., 2023; Palop et al., 2025).

Recent studies have challenged the traditional view that CT is solely a cognitive construct. An increasing body of work argues that CT also involves non-cognitive elements, including learners’ attitudes, dispositions, and mindsets (Román-González et al., 2017, 2018). In addition, a growing body of literature has acknowledged that core CT practices—such as abstraction, iteration, and reuse—play a central role in problem-solving and are applicable across a range of disciplines beyond computing (Barr & Stephenson, 2011; Cheng et al., 2023; Grover & Pea, 2013; ISTE & CSTA, 2011; Plop et al., 2025). A clear distinction is often drawn between CT and programming. While programming is primarily concerned with the technical implementation of code, CT involves higher-order thinking skills (HOTS)—such as analysis, synthesis, and evaluation—and structured problem-solving approaches that extend well beyond computer science. As Wing (2006) compellingly argues, CT should be regarded as a core literacy for all learners, not merely a skill relevant to computer scientists or software developers.

2.3 Design Thinking

As with computational thinking, the definition of design thinking (DT) remains contested, marked by overlapping discourses and divergent interpretations across disciplinary boundaries (Cross, 2011; Dorst, 2011). In the context of education, Razzouk and Shute (2012) characterize design thinking (DT) as a structured methodology that fosters creativity, critical thinking, and collaboration in addressing complex, open-ended problems. By contrast, Brown (2008), writing from a business and innovation perspective, conceptualizes DT as a human-centred process focused on generating desirable, feasible, and viable solutions.

Although differing in emphasis, the origins of DT are frequently attributed to empirical research focused on design cognition and methodology (Lawson, 2006; Cross, 2011; Dorst, 2011). From a cognitive perspective, numerous scholars have described DT as a reflection of the mental processes and professional practices commonly observed among expert designers (Kelly & Gero, 2021). In contrast, alternative perspectives have positioned DT more broadly—as a general design theory, an organizational strategy, or a pedagogical framework applicable across diverse contexts (Kimbell, 2011; Hay et al., 2020).

Moreover, DT comprises a set of iterative problem-solving strategies that underpin contemporary professional design practice. However, this perspective increasingly contrasts with more inclusive interpretations that frame DT as a universal mindset applicable across educational, organizational, and social domains (Cross, 2023). The growing prominence of DT within design research and education has been further catalyzed by the influence of institutions such as IDEO and Stanford’s d.School, which have significantly contributed to its diffusion beyond traditional design fields (Henriksen et al., 2020).

2.4 Co-creation

Co-creation, as conceptualized in this study, is not treated as an abstract or holistic phenomenon but rather as a process observable through distinct, interdependent behavioral and cognitive skills. In this context, co-creation is conceptualized as a collective process of generating and refining knowledge artifacts, emphasizing shared responsibility among learners (Bereiter & Scardamalia, 2006, 2010). However, co-creation represents a valuable pedagogical goal; its abstract and multi-dimensional nature presents challenges for classroom implementation and assessment. To address this, the present study draws on the 4Cs framework as both pedagogical pillars and analytic constructs (Thornhill-Miller et al., 2023). These four competencies represent key 21st-century skills and serve as observable and actionable dimensions of co-creation in learning settings (Agbo et al., 2021; Cook-Sather & Matthews, 2021). By operationalizing co-creation through the 4Cs, this study provides a structured lens to examine how design and computational thinking activities cultivate learners' capacity to engage meaningfully in knowledge co-creation. Keys dimension of co-creative learning, as follows:

- Creativity reflects the learner's capacity to generate, refine, and implement novel ideas in response to complex problems.
- Critical thinking is the ability to analyse problems, evaluate alternatives, and justify decisions collaboratively.
- Communication captures students' use of questioning, reasoning, and elaboration to build shared understanding.
- Collaboration involves task coordination, mutual regulation, and the co-construction of knowledge and artefacts.

Overall, these competencies serve as reliable proxies for tracking co-creation in action within both observational and self-report contexts—and correspond to measurable outcomes at Levels 1 and 2 of the New World Kirkpatrick Model (Kirkpatrick & Kirkpatrick, 2016).

2.5 Project-based learning

Since the 1990s, PjBL has been widely recognised as a student-centred approach that promotes learning by resolving authentic problems (Barak,2020). Blumenfeld et al. (1991) noted that its effectiveness depends on well-designed tasks and supportive technology. Scarbrough et al. (2004) further argue that successful PBL requires overcoming organisational "learning boundaries" to enable reflective knowledge integration, while Ayas and Zeniuk (2001) position PBL as a catalyst for organisational learning and innovation. Recent studies have explored the benefits of integrating CT and DT within PjBL to foster analytical and creative capabilities. For instance, Kelly and Gero (2021) propose a dual-process model in which CT and DT act as complementary modes of problem-solving—structured analysis and human-centred innovation—supporting cross-disciplinary transfer. This dual-process model has been linked to enhanced learner engagement and instructional relevance, especially when embedded in interdisciplinary PBL environments. Empirical studies provide growing evidence for the benefits of this convergence. Apiola and Sutinen (2021) demonstrate that CT and DT integration within PBL cultivates technical competence and systems thinking, while Wang and Wang (2024) report that using machine learning tools in design courses significantly enhances student motivation and computational reasoning.

This integrated model has demonstrated effectiveness in primary education contexts (zhang et al., 2024). A meta-analysis by Zhang, Guan, and Hu (2024) confirms that PBL improves collaboration, creativity, and algorithmic thinking among young learners. Li et al. (2021) find that design-based learning using Scratch enhances CT self-perception, and Valls Pou et al. (2022) highlight how educational robotics within PBL strengthens systems thinking and STEM skills. As illustrated in **Fig**, the integration of CT and DT within a PjBL environment is conceptualized as an iterative, multi-layered pedagogical framework. The diagram illustrates how distinct phases of CT—decomposition, pattern recognition, abstraction, and algorithmic thinking (Wing, 2006)— map to core PBL tasks, such as problem definition, investigation, planning, and testing. Concurrently, DT stages—empathise, define, ideate, prototype, and test (Brown, 2008, 2009)—are mapped onto the same project trajectory, reinforcing human-centred inquiry and creative iteration. This visual model thus encapsulates a dynamic, cyclical process in which analytical and design-oriented strategies coalesce to foster deep, situated learning and co-creation.

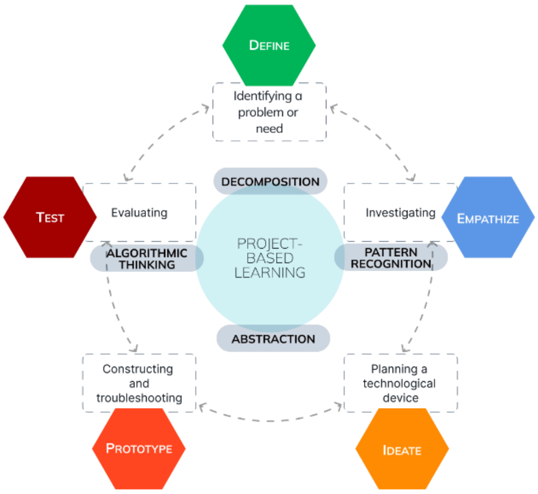


Figure: Integrating Computational Thinking and Design Thinking within Project Based Learning Environments (Source. Adapted from Barak,2020; Brown, 2008,2009; Wing, 2006)

2.6 The integrated computational thinking and design thinking module

The CT–DT module offers a structured co-creation framework for primary-level learners. Recent studies have demonstrated that this integrated approach supports students throughout the problem-solving process, from problem identification to the formulation of effective solutions (Kelly & Gero, 2021; Koh et al., 2015). Building on these findings, the integrated CT–DT framework guides learners' engagement with complex tasks by simultaneously fostering analytical reasoning and creative ideation. The module aimed to enhance co-creation for addressing authentic, real-world wicked problems by drawing upon teacher facilitation, technological scaffolds, and collaborative project-based activities. Throughout the learning sequence, students are guided through tasks such as problem definition, ideation, prototyping, feedback exchange, and iterative refinement (Agbo et al., 2021; Chang et al., 2023). By engaging in these CT–DT practices, students develop the capacity to address complex, ambiguous problems, often referred to as “wicked problems”, by combining algorithmic reasoning with user-centered creative processes (Buchanan, 1992). Drawing on co-creation frameworks, the module implemented in problem-based learning (PBL) environment with gamification, and visual tools, to encompass the five phases of DT (empathize, define, ideate, prototype, test) and core CT competencies (decomposition, abstraction, algorithm design, debugging). For instance, students iteratively construct prototypes, engage in team dialogue, author design logic, and enhance their solutions through tools such as Miro, Scratch, or App Inventor (Chen &Huang, 2017; da Cruz Alves et al., 2020 ; Wardak et al., 2024). This pedagogical design rests on the co-evolution of problem and solution spaces (Crilly, 2021), enacted through project contexts in which empathy and CT logic drive iterative refinement (Chang et al., 2023; Guaman-Quintanilla et al., 2020). Integration of CT—through sequencing and algorithmic thinking—and DT—via empathy and ideation—ensures that during ideation, abstracted user insights inform computational designs, while prototyping transforms these into executable, logic-grounded artefacts (Jun et al., 2017; Agbo et al., 2021). Each design iteration reinforces competencies in both domains through reflection and revision (Yalçın & Erden, 2021). Furthermore, the CT–DT module nurtures both individual agency and collective knowledge construction in technology-mediated classrooms, consistent withconstructivist theories in which artefact creation and refinement within social contexts promote deeper learning.

Error! Reference source not found. outlines the structure of the CT–DT module, which was developed using a PjBL approach to promote co-creation and active participation among primary pupils. Delivered over seven weeks, the module comprised one session per week for a Year 3 class of 35 students. Each session was mapped to specific learning objectives, instructional content, CT skills, DT phases, and teaching methods.The module commenced with activities designed to cultivate empathy and support problem framing, and subsequently progressed to ideation and prototyping through collaborative, hands-on tasks. In the final stages, emphasis was placed on testing, iterative refinement, and reflective practice, culminating in student-led presentations. As shown in the **Error! Reference source not found.**, the module integrates CT and DT components in a systematic manner, thus facilitating the development of problem-solving competencies.

A CT–DT PjBL module mplies a practical approach for fostering primary students' 21st-century skills. Each instructional design phase—from empathy-building to iteration—was explicitly mapped to corresponding CT and DT competencies, such as decomposition, abstraction, and debugging, alongside the structured five-phase DT model. This integration offers a systematic yet flexible instructional framework that supports both analytical reasoning and creative ideation.

Empirical studies suggest potential benefits of integrating CT and DT in primary education contexts. example, Nordby et al. (2024) observed that CT tools like Scratch and block-based programming enhance computational proficiency and domain learning when thoughtfully embedded in project-based activities (Nordby et al., 2024). Similarly, Sari et al. (2024) found that embedding CT into collaborative PBL significantly improved students' perceptions of real-world relevance and their conceptual and problem-solving abilities. Furthermore, Hutchins et al. (2019) and Grover& Pea (2018) demonstrated that CT skills (e.g. abstraction and algorithmic thinking) have the potential to effectively teach in early childhood through hands-on and digital hybrid models, paving the way for early STEM engagement.

Thus, the CT–DT module, when combined with digital tools (e.g., Miro, Padlet, Scratch) and framed within project-based, real-life learning scenarios such as time management, serves not only as a pedagogical innovation but also as a scalable model for cultivating essential cognitive and behavioral competencies in the digital age.

Table 1: CT–DT PjBL Module: Time Organization

Module	**Learning Objective**	**Instructional Content**	**CT Skills**	**DT Phase**	**Instructional Method**
Module 1. Warm-Up & Empathy	Recognise personal patterns of time use	"Where does my time go?" activity	Data collection, pattern recognition	Empathise: perspective-taking	Problem posing, group discussion
Module 2. Problem Framing	Identify time-wasting behaviours and inefficiencies	Analyse time logs using visual tools (e.g., graphs, timelines)	Decomposition, abstraction	Define: framing meaningful problems	Visual analysis, collaborative mapping
Module 3. Idea Generation	Generate actionable strategies for time improvement	Brainstorm "timesaving" strategies	Logical sequencing, pattern finding	Ideate: creative solution generation	Collaborative learning
Module 4. Prototype Development	Construct a personalised time management tool	Develop a timetable, app mock-up, or reminder cards	Algorithm design, stepwise thinking	Prototype: build tangible outputs	Hands-on PjBL
Module 5. Testing & Feedback	Evaluate functionality and receive peer feedback	Peer reviews and usability testing	Debugging, iterative refinement	Test: validate and revise solutions	Peer formative assessment
Module 6. Reflection & Iteration	Reflect on time habits and improve the prototype	Reflective journaling and prototype revision	Problem analysis, iteration	Reflect & Iterate: refine solutions	Reflective writing, self-assessment
Module 7. Final Presentation & Feedback	Present final tools and reflect on learning	Group presentations, peer and teacher feedback	Communication, synthesis	Share: communicate and consolidate learning	Presentation, teacher feedback, self-reflection

Note: 7 Sessions × 45 minutes

2.7 Learning module evaluation

To ensure methodological replicability, the CT–DT module was evaluated using a theoretically grounded framework. As highlighted in the literature, well-structured evaluation processes validate the impact of educational interventions and provide critical insights into their scalability and sustainability (Yadav et al., 2014). This study established evaluation criteria grounded in clear procedural guidelines and evidence-based benchmarks to ensure methodological integrity. Accordingly, two core evaluative criteria were proposed to guide the assessment process:

2.7.1 Engagement in the Classroom

The criterion of engagement aims to assess learners' subjective experiences, focusing on their emotional investment, perceived relevance, and overall satisfaction within the CT–DT learning environment. Drawing on Level 1 of the NWKM, students' immediate reactions are regarded as foundational indicators of instructional effectiveness, offering early insights into the quality and impact of the learning experience (Kirkpatrick & Kirkpatrick, 2016; Yadav et al., 2014).

2.7.2 Performance in Skill Development

The criterion of performance aims to assess students' cognitive skills development, particularly in critical thinking and creativity. Assessment involves evaluating the extent to which learners have acquired conceptual understanding and practical competence within these domains. This form of evaluation corresponds to Level 2 of the NWKM, which measures actual learning outcomes and provides evidence of the instructional intervention's substantive impact (Yadav et al., 2014).

Overall, these complementary criteria enable a comprehensive and systematic evaluation of the module's feasibility and usability by capturing learners' affective engagement and quantifiable learning outcomes. This integrated approach supports a nuanced, evidence-informed understanding of the pedagogical benefits, guiding ongoing refinement and facilitating wider educational adoption.

2.8 Children as Epistemologists

Recent studies have framed children as active knowledge constructors or epistemologists — individuals who construct meaning through metacognitive reflection and the regulation of their learning processes (Papert, 1980). Such a conceptualisation signifies a marked departure from traditional transmission-based models, which depict learners as passive recipients of externally delivered knowledge. The growing emphasis on learner agency has contributed to a broader theoretical orientation towards cognitive constructivism, which views learning as a dynamic interaction between the individual and their environment (Piaget, 1970). In parallel, alignment with social constructivist perspectives underscores the importance of cultural tools, language, and interpersonal dialogue in shaping cognitive development (Vygotsky, 1978; Kalina & Powell, 2009). Vygotsky's concept of the Zone of Proximal Development (ZPD). In particular, it has been widely invoked to illustrate how learning is mediated through collaboration with more knowledgeable others, thus reinforcing the principle that knowledge is constructed both individually and socially (Wertsch, 1988; Chevalier et al., 2021; He et al., 2023).

In this evolving paradigm, research focus has shifted from what children learn to how learning occurs, including the processes and conditions that enable deep engagement and meaningful knowledge construction (Dolmans et al., 2016; Loynes et al., 2009; Ritoša et al., 2023). Central to this perspective is the emphasis on learners' agency, self-regulation, and capacity to actively generate knowledge, moving beyond passive consumption. Building upon this foundation, Papert (1980) advanced the theory of constructionism, an extension of Piagetian constructivism, which posits that learning is optimised when learners are actively involved in creating meaningful artefacts—ranging from computer programmes to robotic devices. Empirical investigations substantiate this claim; for example, Smith et al. (2018) demonstrated that primary school pupils engaged in designing and debugging robotic systems exhibited significant improvements in problem-solving skills and a more profound conceptual grasp of underlying principles. Constructionist learning environments, therefore, are characterised by hands-on experimentation, reflective practice, and iterative design cycles, fostering profound cognitive engagement.

This learner-centred approach aligns with Dewey's (1938) emphasis on experiential learning and Schön's (1983) advocacy of reflective practice. In short, these perspectives highlight the pivotal role of context, lived experience, and critical reflexivity in shaping meaningful learning (Pande & Bharathi, 2020). Overall, these frameworks advance the view that children are capable of actively directing their own learning trajectories through creative exploration and reflective engagement.

Conversely, Bereiter and Scardamalia's (2010) Knowledge Building framework offers an alternative yet complementary perspective on children's epistemic agency by emphasising collaborative inquiry within a community of learners. This model de-emphasises individual creativity in favour of the co-construction of knowledge through sustained dialogue, iterative idea improvement, and shared intellectual responsibility. Zhang et al. (2011) provided supporting evidence for this approach, who observed that primary students involved in extended writing and theory refinement tasks within the Knowledge Forum platform generated original scientific ideas and significantly advanced their conceptual understanding through peer feedback and collaborative discourse.

In conclusion, while Paper (1980)'s constructionism prioritizes learning through individual creation and making, Bereiter and Scardamalia(2010)'s knowledge-building model foregrounds distributed cognition and collective knowledge advancement. These paradigms embody divergent, yet ultimately complementary, conceptualisations of learning processes—whether emerging primarily through personal, exploratory engagement or socially mediated, collaborative discourse.

3. Method

3.1 Participants

This study employed purposive sampling to recruit a single Grade 3 class (N = 35; 18 boys, 17 girls) from a public primary school in Kunming, Yunnan Province, China. The participants were enrolled in an after-school program aimed at fostering co-creation. School staff nominated students for Olympiad training based on academic performance and demonstrated engagement in cognitively demanding inquiry-based tasks. These selection criteria were consistent with the cognitive demands of the CT–DT integrated PjBL intervention. Table 1 presents the participants' demographic characteristics.

The participant group represented diverse socio-economic backgrounds, including local urban families and children of rural-to-urban migrant workers (See Table 1). Parental occupations ranged from civil service and corporate employment to manual labour, with considerable variation in educational attainment and capacity to support their children's learning due to occupational demands (e.g., rotating or night shifts). Founded in the mid-20th century and widely recognised for academic excellence, the school provides weekly science-focused instruction, well-resourced classrooms, and access to enriched learning materials. These features made the setting pedagogically suitable for studying collaborative learning.

A mixed-methods approach was adopted, incorporating both qualitative and quantitative data collection consistent with the first two levels of the New World Kirkpatrick Model (NWKM)—namely, Level 1: Reaction (capturing learner engagement and affective responses, particularly students' experiences of communication and collaboration) and Level 2: Learning (assessing gains in knowledge and skills, specifically in critical thinking and creativity). These levels are particularly appropriate for short-term assessments of learner responses and knowledge acquisition (Kirkpatrick & Kirkpatrick, 2016), especially during the early stages of instructional design (Bates, 2004; Cook-Sather & Matthews, 2021; Lin & Van Brummelen, 2021).

Level 1 (Reaction) focused on capturing students' behavioral engagement and collaborative interactions throughout the CT–DT module. To address this, qualitative data were collected via semi-structured classroom observations conducted during each session. This method yielded contextual insights consistent with Level 1 of the NWKM, capturing learners' initial reactions and engagement. Given the developmental stage of primary learners and their limited capacity to articulate experiences through standardised self-report measures, classroom observation was considered a developmentally appropriate and ecologically valid approach (Ritoša et al., 2023).

In turn, Level 2 (Learning) focused on evaluating students' cognitive development following the intervention. A single-group pretest–posttest design was adopted to assess changes in two core domains: critical thinking and creativity. To this end, the Learning and Innovation Skills – Self-Efficacy Scale (LIS-SES; Kayhan & Korkmaz, 2024), a validated instrument based on the P21 Framework for 21st Century Learning, was administered. The scale includes representative items such as "I can analyse situations from multiple perspectives" and "I can generate new ideas to solve problems," rated on a 5-point Likert scale. Internal consistency was high (Cronbach's α = 0.936), supporting the scale's reliability and appropriateness in primary education contexts.

The study followed institutional ethics protocols and obtained prior approval for research involving minors. Before data collection, the school's leadership team provided formal approval. To ensure curricular alignment and ethical compliance, faculty and school administrators reviewed all instructional materials and consent documentation, including the CT–DT module.

A Participant Information Sheet (PIS) was distributed to pupils and their guardians to safeguard participant autonomy and ensure informed, voluntary participation, detailing the study's aims, procedures, and voluntary nature. Informed consent was secured through the following measures:

Pupil Assent: Each child completed an age-appropriate assent form to indicate understanding and voluntary agreement.
Parental Consent: Written consent was obtained from legal guardians, which in turn authorized their child's participation.

In summary, these procedures were undertaken to protect participants' welfare and to ensure compliance with institutional and educational ethical standards.

Table 1: Participant Demographic Information

Item	**Details**	**Frequency**	**Percentage**
Group	A/single Groups of 30 students in China	35	100%
Gender	Male	20	57.1%
	Female	15	42.9%
Grade level/Age groups	8 years old pupils in 3rd grade	17	48.6%
	9 years old pupils in 3rd grade	18	51.4%
Geography of Students' Family	Yunnan, China	32	91.4%
	Other city of China	3	8.6%
Hometown of Students' Family	Urban	30	85.7%
	Rural	5	14.3%
Total Monthly Income of Students' Family	Under 10000 RMB	3	8.6%
	10000-20000 RMB	25	71.4%
	Above 20000 RMB	7	20%
Father's occupation	Government employee	12	34.3%
	Employee of the State Establishment	11	31.4%
	Private sector employee	7	20%
	Self-employed	2	5.7%
	Freelance workers	1	2.9%
	Others	2	5.7%
Mother's occupation	Government employees	7	20%
	Employee of the State Establishment	18	51.4%
	Private sector employees	5	14.3%

	Self-employed	1	2.9%
	Freelance workers	3	8.6%
	Others	1	2.9%
Father's Level of Pedagogy	High school and below	3	8.6%
	College	5	14.3%
	Bachelor’s degree	9	25.7%
	Master and above	18	51.4%
Mother's Level of Pedagogy	High school and below	2	5.7%
	College	5	14.3%
	Bachelor’s degree	8	22.9%
	Master and above	20	57.1%

3.2 Measurements

As shown in

Figure 1 and **Figure 2**, this study adopted mix-method within two levels of the NWKM, Level 1 (Reaction) and Level 2 (Learning), to assess the learning outcomes of the CT–DT PjBL module. These levels examine engagement and skills development, respectively (Moreau, 2017). Drawing upon established frameworks of 21st-century skills (e.g., Trilling & Fadel, 2009), in contemporary collaborative learning discourse, co-creation is increasingly conceptualised as a pedagogical process underpinned by the development of core 21st-century competencies, most notably encapsulated in the 4Cs framework, namely communication, collaboration, critical thinking, and creativity. Unlike traditional learning methods, which typically position learners as passive recipients of knowledge, co-creation in collaborative learning emphasizes knowledge sharing, co-design, and the joint construction of meaning within authentic learning contexts (Trilling & Fadel, 2009). The 4Cs are the key foundation for co-creation and continue to develop throughout the co-creation process. (Lucas et al.; 2013; Poutanen & Parviainen, 2013; Sailin & Mahmor, 2017). Therefore, the 4Cs in 21st-century skills are widely recognized as foundational to co-creation processes. This study adopted four core dimensions that underpin co-creation: (1) Communication（e.g., questioning, responding, emotional support）, (2) Collaboration（e.g., peer assistance, co-design, joint task execution), (3) Critical Thinking (e.g., logical analysis, reasoning, evaluating alternatives), (4) Creativity (e.g., ideation, implementation, iteration). Overall, these interdependent capabilities represent the behavioural and cognitive dispositions essential for knowledge-creation and generating innovative solutions, particularly within PjBL and CT–DT integrated environments (Thornhill-Miller et al., 2023).

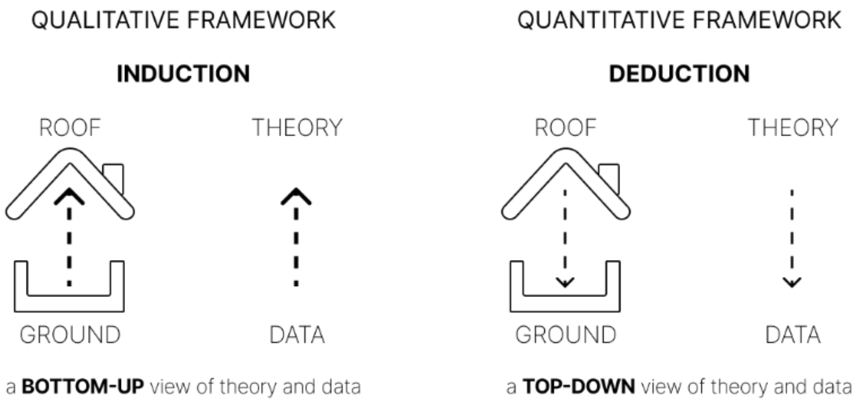


Figure 1: A Mixed Methods Analytical Framework: Integrating Inductive and Deductive

Approaches. Source: Adapted from Yin (2006); Creswell & Plano Clark (2017); Johnson & Onwuegbuzie (2004)

3.2.1 Engagement

To assess students' engagement during the CT–DT PjBL intervention, this study adopted Level 1 (Reaction) of the NWKM, focusing on two key behavioural constructs: communication and collaboration. These dimensions are widely acknowledged as fundamental to co-creation and are embedded within 21st-century learning competencies (Trilling & Fadel, 2009; Voogt & Roblin, 2012). Specifically:

- Communication：is typically defined as the ability to articulate ideas clearly, engage in active listening, and provide constructive feedback (Trilling & Fadel, 2009; Voogt & Roblin, 2012).
- Collaboration： is commonly conceptualised as cooperative task engagement, grounded in mutual respect and shared responsibility (Van Mechelen et al., 2019; Voogt & Roblin, 2012).

Thus, to assess these dimensions, formative assessment (e.g., classroom observations and teacher log reflections) was employed across the seven-week intervention, providing qualitative insights into behavioral engagement indicators. Each 45-minute weekly session required students to engage in collaborative problem-solving tasks grounded in CT and DT principles, enhancing authentic inquiry, active involvement, peer interaction, and iterative co-construction of knowledge. First, this study conducted classroom observations during each 45-minute session, with field notes capturing real-time indicators of interaction quality and group dynamics. Second, following each session, teachers completed structured logs detailing student participation, including who initiated communication, the responsiveness of peers, and how collaborative roles were negotiated within each group.

Using dual observation sources enabled the triangulation of qualitative data, thus enhancing the trustworthiness of the findings. This approach is particularly appropriate in primary education contexts, where learners often lack the metacognitive and linguistic maturity required for reliable self-reporting (Ritoša et al., 2023). Furthermore, these observational instruments captured engagement as situated and co-constructed within the learning environment.

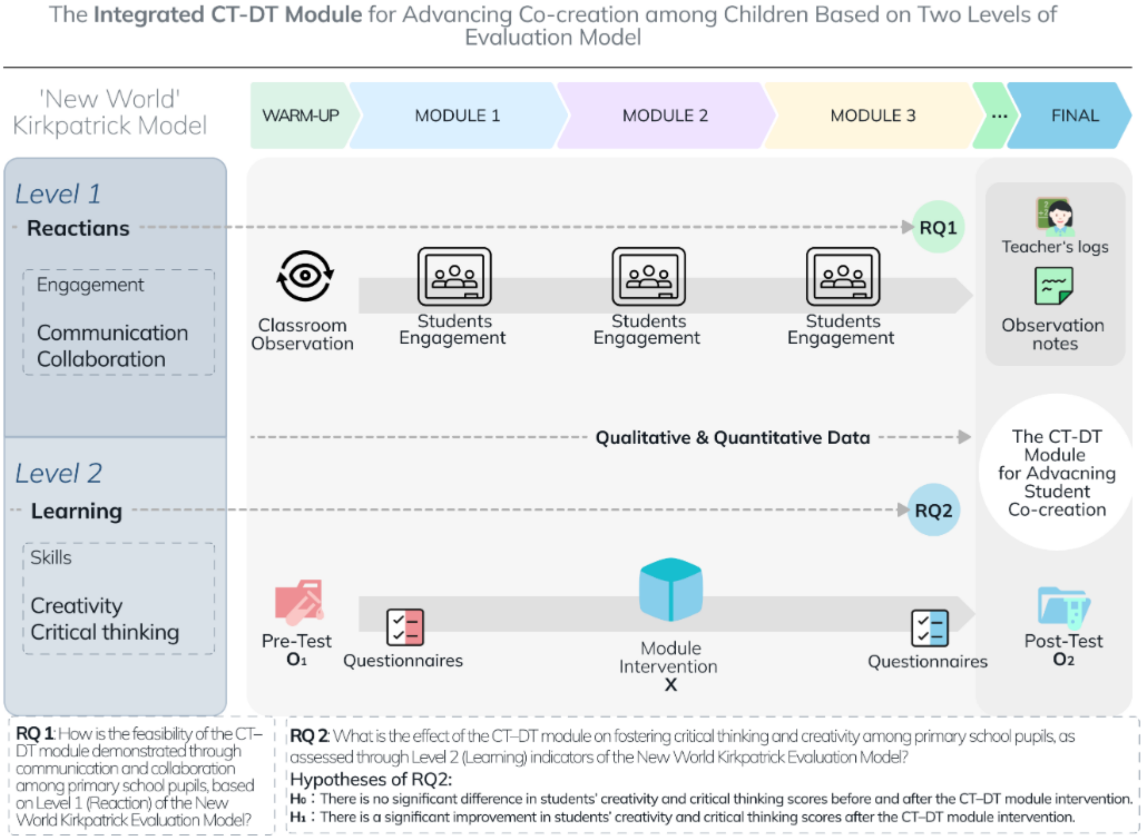
3.2.2 Skills

To evaluate the development of students’ cognitive skills—namely critical thinking and creativity—this study employed a single-group (N = 35) pre-test and post-test design. This within-subject approach allowed for the assessment of changes over time without the inclusion of a comparison group. Two core dimensions were examined:

- Critical thinking：is commonly defined as the ability to analyse information logically, assess alternatives, and form reasoned judgments (Trilling & Fadel, 2009; Voogt & Roblin, 2012).
- Creativity：is commonly defined as the ability to generate innovative ideas, exhibit cognitive flexibility, and refine solutions through iterative processes (Trilling & Fadel, 2009; Voogt & Roblin, 2012).

Baseline data were obtained during the initial face-to-face session using the LIS-SES, a validated self-report measure grounded in the P21 Framework (Kayhan & Korkmaz, 2024). The scale demonstrated high internal consistency (Cronbach’s $\alpha = 0.936$) and was selected for its suitability for assessing perceived competencies in 21st-century learning among students. The pre-test functioned as a baseline measure of students’ initial cognitive competencies, providing a reference point against which post-test scores—collected in the final session—were compared to identify learning gains attributable to the seven-week integrated CT–DT module in the PjBL environment.

To mitigate potential confounding variables (e.g. discrepancies in lesson content or instructional exposure), a structured, performance-based quiz was administered at both the pre- and post-intervention stages. This instrument, explicitly grounded in the core thematic focus of the intervention (i.e., the time organization project), provided an additional objective measure of learners' ability to apply acquired knowledge and demonstrate cognitive progression. Its inclusion strengthened the triangulation of self-reported data, thus enhancing the methodological rigor of the study. Creativity and critical thinking are conceptualized as core cognitive and dispositional constructs that underpin meaningful knowledge construction and innovation. These constructs are central to CT–DT–PjBL frameworks, which emphasize iterative design processes and co-creative problem-solving. As Thornhill-Miller et al. (2023) contend, such frameworks depend on learners' capacity to engage critically and creatively with open-ended, real-world challenges.



RQ 1: How is the feasibility of the CT–DT module demonstrated through communication and collaboration among primary school pupils, based on Level 1 (Reaction) of the New World Kirkpatrick Evaluation Model?

RQ 2: What is the effect of the CT–DT module on fostering critical thinking and creativity among primary school pupils, as assessed through Level 2 (Learning) indicators of the New World Kirkpatrick Evaluation Model?

Hypotheses of RQ2:
H_0 : There is no significant difference in students' creativity and critical thinking scores before and after the CT–DT module intervention.
H_1 : There is a significant improvement in students' creativity and critical thinking scores after the CT–DT module intervention.

Figure 2 : Illustration of the integrated CT-DT module for advancing co-creation among elementary students

3.2.3 Evaluation Process and Instruments

Figure 3 outlines the evaluation framework adopted in this study, which integrates the CT–DT module with the first two levels of the NWKM —Level 1 (Reaction) and Level 2 (Learning). These levels are mapped onto the study's research questions (RQ1 and RQ2) and investigated using qualitative and quantitative data collection methods. As illustrated in the **Figure 3**, formative evaluation through classroom observation was employed to assess students' reactions (Level 1). At the same time, a pre-test and post-test design was implemented to assess learning outcomes (Level 2). The model further acknowledges that Levels 3 (Behaviour) and 4 (Results) were excluded from the present evaluation due to the short-term duration of the intervention. However, future studies are anticipated to incorporate longitudinal evaluation to explore these higher-level impacts. This study operatively implemented these levels through formative and summative evaluation strategies to explore student engagement and cognitive development.

- Formative Evaluation (Level 1: Reaction)

To address RQ1, this study focused on students' collaborative and communicative behaviors during CT–DT activities, reflecting Level 1 (Reaction) of the NWKM. To assess these behaviours, the class teacher, alongside trained researchers, carried out semi-structured classroom observations throughout each module. These observers systematically documented task coordination, idea exchange, feedback provision, and emotional expression through structured field notes. Subsequently, these notes were imported into NVivo 14 for qualitative analysis. Thematic coding was employed to discern recurrent behavioural patterns(Vaismoradi et al., 2013; Xu & Zammit, 2020). These patterns were categorised into two overarching dimensions: collaboration (e.g., peer assistance, joint task completion) and communication (e.g., questioning, responding, emotional support). Following identifying key themes, content analysis was conducted to quantify the frequency of each behaviour across all seven modules. This approach enabled the researchers to track student engagement and interaction shifts over time(Constantinou et al. ,2024; Al Mamun and Lawrie ,2023).

Table 2 outlines six themes derived from thematic analysis, categorised under two core behavioural dimensions: *Communication* and *Collaboration*. Each theme represents specific learner behaviours observed during the CT–DT PjBL sessions, including problem framing, ideation, co-design, and implementation. These observed practices reflect core principles of co-creative learning and are anchored in well-established literature (e.g., Scardamalia & Bereiter, 2006; Sanders & Stappers, 2008).

- Summative Evaluation (Level 2: Learning)

To address RQ2, the study examined whether the CT–DT intervention produced measurable gains in students' critical thinking and creativity—two key cognitive competencies aligned with Level 2 (Learning) of the NWKM. A single-group pre-test and post-test design was employed, as this method is widely acknowledged as suitable for authentic classroom settings in which random assignment is impractical (Trochim & Spiegelman, 2002). Accordingly, participants first completed a baseline assessment (O_1), engaged in a structured sequence of seven instructional modules (X), and subsequently completed a post-test (O_2) to evaluate changes in learning outcomes.

To assess these competencies, the study employed the LIS-SES, developed by Kayhan and Korkmaz (2024), as shown in **Table 3**. Grounded in the P21 Framework for 21st-century Learning, the instrument includes items such as "I can analyse situations from multiple perspectives" (critical thinking) and "I can generate new ideas to solve problems" (creativity), each rated on a 5-point Likert scale. The scale demonstrated a high level of internal consistency within the sample (Cronbach's $\alpha = 0.936$), thus confirming its reliability for use in primary education contexts.

For data analysis, quantitative responses were examined using SPSS version 25.0. Pair-samples t-tests were conducted to evaluate the statistical significance of changes between pre- and post-intervention scores. Furthermore, effect sizes were calculated using Cohen's d (1988), enabling the researchers to determine the magnitude of any observed improvements.

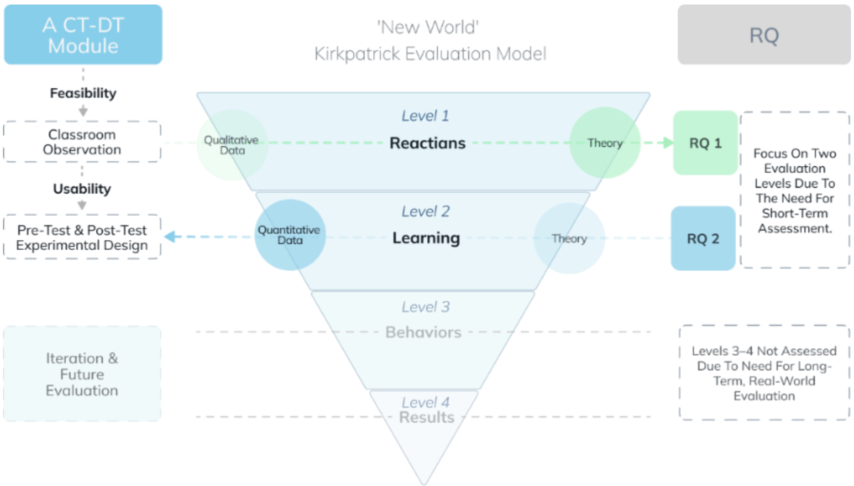


Figure 3: Module Evaluation

3.3. Data analysis

3.3.1 Qualitative data analysis

As shown in **Figure 4**, this study followed Braun and Clarke's (2006) six-phase procedure for thematic analysis, which includes: (1) familiarization with the data, (2) generating initial codes, (3) searching for themes, (4) reviewing themes, (5) defining and naming themes, and (6) producing the report.

Qualitative data were primarily collected through systematic classroom observations and teacher logs, which assessed real-time learner behaviors and collaborative interactions within authentic classroom environments. These forms of documentation have been widely acknowledged for their capacity to yield rich, context-specific insights into participant experience (Burnard et al., 2008). Thematic analysis was subsequently employed to inductively interpret the recorded accounts, allowing for the identification of recurring patterns consistent with the study's research objectives. Given the young age of participants, observation was adopted as a more appropriate method than self-report instruments. This approach enabled the identification of subtle non-verbal cues and affective responses that primary-aged pupils often struggle to articulate verbally (Ritoša et al., 2023). Moreover, the chosen approach aligned with Level 1 (Reaction) of the NWKM (Kirkpatrick & Kirkpatrick, 2016), which highlights learners' emotional engagement, motivation, and perceived relevance of the instructional experience.

The study employed a triangulated qualitative approach to evaluate the feasibility of the CT–DT integrated intervention and learners' engagement. Which involved synthesizing systematic classroom observations with reflective commentaries provided by the class teacher, thus incorporating practitioner perspectives and reinforcing the interpretive trustworthiness of the findings (van Leeuwen & Janssen, 2019).

The qualitative data analysis followed a two-stage process. First, the study employed thematic coding guided by a predefined analytical framework centered on collaborative and communicative behaviours. This phase identified salient indicators such as verbal exchanges, joint task execution, and observable cooperation (Mifsud & Nordby, 2025). Second, comparative and inductive analyses were conducted to examine these behaviors' recurrence and temporal patterns across multiple sessions. Frequency counts were used to support inductively derived propositions and to identify emerging developmental trends. This triangulated analytical strategy strengthened the study's internal validity by reducing observer bias and enhancing methodological rigour (Palinkas et al., 2015; Tonkin-Crine et al., 2015).

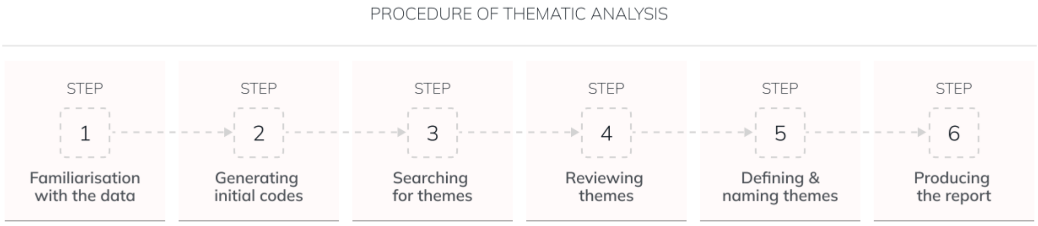


Figure 4: Procedure of thematic analysis. Source: Adapted from Braun & Clarke. 2006

Table 2 : Inductive Thematic Coding Scheme for Analysing Reaction-Level Data from Classroom Observations and Teacher Logs

	Code	**Theme Label**	**Representative Behaviour**	**Description**	**Key Citations**
Dimension 1 Communication	R1	Shared Problem Framing	Questioning, posing challenges	Pupils collectively interpret and redefine the problem space by raising questions, surfacing ambiguities, and connecting to real-world contexts.	Sanders & Stappers (2008); Carroll et al. (2010); Scardamalia & Bereiter (2006)
	R2	Distributed Ideation	Responding, proposing ideas, refining	Pupils collaboratively construct ideas through a process in which contributions are successively expanded, challenged, and synthesised by peers, typically moving from divergent thinking to convergent outcomes.	Resnick et al. (2015); Hmelo-Silver et al. (2007); Kafai & Burke (2015)
	R3	Dialogic Meaning-Making	Collaborative dialogue, emotional support	Pupils engage in sustained dialogue to co-construct understanding, using reasoning, elaboration, and empathy to support shared cognition.	Mercer & Littleton (2007); Wegerif (2011); Scardamalia & Bereiter (2006)
Dimension 2 Collaboration	R4	Collaborative Regulation	Reciprocal adaptation and shared monitoring	Pupils jointly monitor project goals, adjust individual contributions, and negotiate task strategies—mirroring self-	Järvelä & Hadwin (2013); Volet et al. (2009); Hmelo-Silver et al. (2007); Resnick (2017)

				regulated and socially shared regulation in co-creative design and computational tasks.	
	R5	Participatory Co-Design	Joint ideation, sketching, prototyping, and revising	Pupils engage in the co-development of artefacts by proposing ideas, visualizing solutions, building and testing prototypes—reflecting the iterative nature of DT and distributed creativity.	Sanders & Stappers (2008); DiSalvo et al. (2017); Razzouk & Shute (2012); Kafai & Burke (2015)
	R6	Co-Implementation of Solutions	Task allocation, tool usage, coding, and building shared outcomes	Pupils collaborated to execute a final solution—allocating roles, coordinating tools, debugging code, and refining outputs. This process reflects the abstraction and implementation phases of CT within collaborative settings.	Brennan & Resnick (2012); Blikstein (2013); Scardamalia & Bereiter (2006); Barron (2003)

Quantitative data analysis

Quantitative data were collected using the LIS-SES, developed by Kayhan and Korkmaz (2024). Grounded in the P21 Framework for 21st Century Learning, the instrument was administered at two time points—pre-test and post-intervention—to assess changes in pupils' self-perceived learning competencies.The analysis focused on two key domains: creativity (e.g., "I can generate new ideas to solve problems") and critical thinking (e.g., "I can analyse situations from multiple perspectives"). All items were rated on a 5-point Likert scale ranging from 1 (Strongly Disagree) to 5 (Strongly Agree). As shown in Table 2, the instrument demonstrated excellent internal reliability with a Cronbach's α of 0.936, indicating strong internal consistency and appropriateness for use with primary school learners.

Figure 5 illustrates the procedural sequence adopted in this study's one-group pre-test and post-test design. Participants initially completed a pre-test (O_1) to establish a baseline, engaged in a structured series of seven instructional modules (X), and subsequently undertook a post-test (O_2) to assess learning gains. This design facilitated the tracking of within-subject changes over time without a comparison group, consistent with established quasi-experimental protocols (Creswell, 2017; Fraenkel et al., 2006).

To evaluate the usability of the CT–DT integrated intervention, the study employed a single-group pre-test and post-test design, enabling the examination of within-subject changes in cognitive self-efficacy throughout the programme. Initial comparisons were conducted using a paired-sample t-test to assess whether differences in mean scores reached statistical significance. However, given the small sample size (N = 35) and the ordinal nature of the Likert-scale data, the Wilcoxon Signed-Rank Test was subsequently employed as a more statistically appropriate non-parametric alternative. This test has been widely adopted when the assumption of normality cannot be confirmed (Field, 2024), and is considered consistent with established analytical approaches for ordinal data in educational research (Jamieson, 2004).

The Wilcoxon test assessed median shifts in pupils' self-efficacy across the two targeted dimensions—critical thinking and creativity. The analysis reported Z-values, p-values, and effect sizes (r) to determine the magnitude and significance of observed changes (Fritz et al., 2012; Pallant, 2020). By combining a theoretically validated measure with appropriate inferential techniques, the study provided a systematic evaluation of the CT–DT intervention's impact on learners' development of 21st-century cognitive skills.

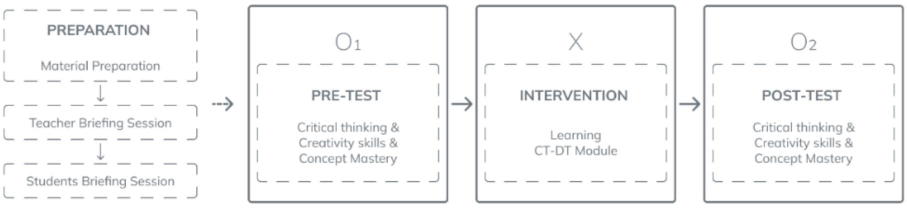


Figure 5: Procedure of Pre-test and Post-test. Source: Adapted from Creswell, 2017; Fraenkel et al., 2006

Table 3: Learning and Innovation Skills Self-Efficacy Scale (LIS-SES)

Factor	Item	Statement	Strongly Disagree (1)	Disagree (2)	Undecided (3)	Agree (4)	Strongly Agree (5)
Dimension 3 Critical Thinking	L1	I can analyse the steps for solving a problem in detail.	(1)	(2)	(3)	(4)	(5)
	L 2	I can analyse in detail different ways of solving a problem.	(1)	(2)	(3)	(4)	(5)
	L 3	I can analyse the relationship between a whole and its parts in detail.	(1)	(2)	(3)	(4)	(5)
	L 4	I can find appropriate solutions for problems that require more than one step.	(1)	(2)	(3)	(4)	(5)
	L 5	I can generate questions about the process to reach better solutions.	(1)	(2)	(3)	(4)	(5)
	L 6	I can reach the most appropriate solution by interpreting the information I have obtained.	(1)	(2)	(3)	(4)	(5)
	L 7	I can make the right decisions by evaluating information critically.	(1)	(2)	(3)	(4)	(5)
	L 8	I can consider alternative ideas on any topic.	(1)	(2)	(3)	(4)	(5)
	L 9	I can solve a problem using what I have learnt.	(1)	(2)	(3)	(4)	(5)
Dimension 4 Creativity	L 10	I can develop new ideas on any subject.	(1)	(2)	(3)	(4)	(5)
	L 11	I can elaborate my ideas to be more creative.	(1)	(2)	(3)	(4)	(5)

	L 12	I value different points of view.	(1)	(2)	(3)	(4)	(5)
	L 13	I can generate new ideas in activities where various idea generation techniques such as brainstorming and six-hat thinking are used.	(1)	(2)	(3)	(4)	(5)
	L 14	I find new ideas on any subject worthy of attention.	(1)	(2)	(3)	(4)	(5)
	L 15	Any ideas I develop on any subject are recognized.	(1)	(2)	(3)	(4)	(5)
	L 16	I can contribute to the development of a new product.	(1)	(2)	(3)	(4)	(5)

Source: Kayhan & Korkmaz, 2024

4. Results

4.1 Level 1: Reaction Level of Evaluation

Regarding the Reaction level of the NWKM, the findings for RQ1 were derived from systematic classroom observations and teacher logs, which were analysed using inductive thematic analysis following Braun and Clarke's (2006) six-phase framework. The research team employed NVivo 14 to code the data, ensuring transparency throughout the analytical process. Across the seven-module CT–DT learning sequence, the analysis identified six distinct behavioural dimensions (R1–R6), as detailed in **Table 2**. These emergent themes assessed pupils' developing collaborative and communicative practices and were theoretically grounded in established literature on collaborative learning and design-based pedagogy (Bereiter, 2006; Kolodner et al., 2003; Scardamalia & Bereiter, 2006).

Table 4 presents the frequency of observed behaviours across seven modules, based on thematic coding of classroom observations and teacher logs (N = 394). Dialogic Meaning-Making (R3, n = 87) and Distributed Ideation (R2, n = 86) were most prevalent, highlighting active peer dialogue and idea exchange. Solution Implementation (R6, n = 24) appeared mainly in later modules, reflecting the iterative trajectory of CT–DT learning.

Table 4: Thematic Coding Frequency Based on Classroom Observations and Teacher Logs

Behavioural Dimension	**M1**	**M2**	**M3**	**M4**	**M5**	**M6**	**M7**	**Total**
R1. Shared Problem Framing	28	22	7	3	2	1	1	64
R2. Distributed Ideation	5	17	20	19	14	7	4	86
R3. Dialogic Meaning-Making	0	5	21	23	25	10	3	87
R4. Collaborative Regulation	0	0	6	19	21	22	4	72
R5. Participatory Co-Design	0	0	3	8	19	25	6	61
R6. Solution Implementation	0	0	0	0	1	6	17	24
Total	33	44	57	72	82	71	35	394

Source: Qualitative data coded from 7 classroom observations (Modules 1–7) and teacher logs; N = 35 students (7 groups, 5 students per group).

4.1.1 R1: Shared Problem Framing

In the early modules (M1–2), pupils relied heavily on teacher scaffolding while interpreting the design problem—developing a time-management application. Notably, 78% of all R1-coded instances occurred during these initial sessions, underscoring early reliance on teacher scaffolding (50 of 64 codes) during M1–2. With minimal peer discussion, observations recorded frequent student queries such as "What should we do?" and "Is this correct?". Teacher reflection logs supported these observations and reinforced the classroom evidence. E.g. "waited for every step" and seldom initiated conversations. By late M2, some pupils began applying personal routines to interpret the task, posing questions like "What do you do after school?" and documenting their wake-up and study times. These early behaviours signalled a transition from teacher-dependent framing towards emergent peer-based contextualisation.

4.1.2 R2: Distributed Ideation

Distributed ideation increased substantially between M2–4, peaking at M3 (20 codes) and M4 (19 codes), accounting for over 65% of all R2-coded behaviours. Pupils began exchanging and building on ideas, evidenced by classroom talk such as "Let us try this one" or "What if we change that part?" Teacher logs described groups "bouncing ideas without waiting for instruction." Variation existed between groups, some generated multiple options collaboratively, while others relied on dominant voices. Nonetheless, progress confirms a clear move from teacher-driven prompting to pupil-led creative exchange.

4.1.3 R3: Dialogic Meaning-Making

Dialogic interactions were initially limited but increased markedly during Modules 3 to 5, accounting for 69 of the 87 R3-coded instances. During this phase, pupils increasingly employed questioning, justification, and elaboration to co-construct shared understanding. Illustratively, students were observed to ask, "Why would this be better?" or offered alternatives: "What problem are we solving here?" Teacher logs observed: "They started to challenge and build on each other's ideas." These practices indicated an emerging epistemic agency—students were no longer simply exchanging ideas, but engaging in deeper dialogic reasoning.

4.1.4 R4: Collaborative Regulation

Beginning in Module 4, pupils progressively demonstrated collaborative regulation strategies—such as coordinating time, distributing tasks, and resolving interpersonal tensions. Notably, this pattern intensified in Modules 5 and 6, which collectively accounted for 43 of the 72 behaviours coded under R4. Observations included dialogue like: "You draw, I will write" or "Let us finish this screen first." In 6 of 7 groups, task coordination occurred without teacher prompts. Teacher entries noted, "They solved disagreements themselves." The reduction in teacher-led regulation—from 100% in M1–2 to below 30% in M6—reveals a transition toward self-managed group work, a key component of sustainable design-based collaboration.

4.1.5 R5: Participatory Co-Design

Participatory co-design behaviours emerged from M4 and were most prominent in M5–6 (44 of 61 R5 codes). Students jointly selected design elements, including app layout, colour schemes, and navigation. Typical expressions included "Let us vote on it" or "How would users feel?" Six of seven groups made key decisions collaboratively and tested initial sketches. Notably, some students sought feedback from peers outside their group. As recorded in teacher logs: "They were not just designing for themselves—they were thinking about others." These behaviours indicate an increasing awareness of user-centred design and shared authorship.

4.1.6 R6: Solution Implementation

Solution-implementation behaviours were predominantly observed in Modules 6–7, with 23 of the 24 instances coded under R6 emerging during this phase. During these sessions, students presented functioning prototypes, which ranged from paper-based mock-ups to app simulations developed using platforms such as Scratch or MIT App Inventor. Collaborative dialogue reflected iterative design refinements: "Let us put the button here" or "Try using it and tell me what is missing." One group simplified their design after peer testing: "It is hard to find the start button," prompting revisions. Teachers highlighted their autonomy: "They tested and fixed things without asking me." This phase demonstrated students' capacity to translate ideas into concrete outputs and iteratively refine their solutions based on feedback.

The qualitative analysis of 394 coded behaviours across seven modules reveals a progressive shift from teacher-directed participation to increasingly autonomous, collaborative, and reflective engagement. While R1 was concentrated in early modules (78% in M1‑2), later behaviors—such as co-design (R5) and solution implementation (R6)—peaked in M5–7. This trajectory indicates that pupils progressively internalised collaborative design practices, providing evidence for the feasibility of CT–DT integration in primary PjBL contexts.

In summary, evidence for the feasibility of the CT–DT module emerged inductively from repeated classroom observations and teacher log analyses, which revealed progressive shifts in students' communication and collaboration over the seven instructional modules. These evolving behavioural patterns offer grounded insights into learners' social engagement and interactive practices during the intervention.

In the early modules (M1–M2), students actively engaged in shared problem framing (R1), collaboratively interpreting open-ended tasks, and co-constructing a shared understanding of project goals. This behaviour—characterised by gesturing, questioning, and verbal negotiation—suggests an intuitive inclination toward collective inquiry and meaning-making. From modules M3 to M5, instances of distributed ideation (R2) and dialogic meaning-making (R3) increased noticeably. Students began building upon peers' ideas through sustained verbal exchanges and visual co-representation, indicating the emergence of epistemic trust and dialogical reasoning. These interactions also shifted from teacher-directed prompts to peer-led elaboration and ideation.

The observed trajectories of social interaction align closely with constructionist learning theory (Papert, 1980), emphasizing collaborative artifact creation's value in fostering deep conceptual understanding. Furthermore, the emergence of peer regulation and shared authorship resonates with Bereiter and Scardamalia's (2003) knowledge-building framework, in which collective responsibility and iterative idea refinement are central to cognitive growth. Overall, these findings support the claim that CT‑DT integration within project-based settings can scaffold authentic, learner-driven co-creation processes in primary education.

The observed behaviours provide empirical support for the feasibility and social value of the CT–DT module, reflecting Level 1 outcomes in the NWKM (Kirkpatrick & Kirkpatrick, 2006).

4.2 Level 2: Learning Level of Evaluation

To evaluate the intervention's learning-level outcomes, this study employed a one-group pretest–posttest design with 35 primary school students. Given the ordinal nature of the data and its non-normal distribution, the Wilcoxon Signed-Rank Test was used as a suitable analytical approach. To assess statistically significant differences between pre-test and post-test scores across the dimensions of Critical Thinking and Creativity (Ghasemi & Zahediasl, 2012).

Table 5 reports the means (M) and standard deviations (SD) for each construct, measured before and after the intervention. Across all domains, students demonstrated marked increases in performance, suggesting that the CT–DT module contributed positively to the development of HOTS.

Table 5: Wilcoxon Test Results for Pre- and Post-Test Scores (N = 35)

Dimension	Pre-Test (M ± SD)	Post-Test (M ± SD)	Z	p-value	Effect Size (r)	Interpretation
Critical Thinking	2.51 ± 0.42	3.42 ± 0.47	-5	< .001	0.6	Large improvement
Creativity	2.47 ± 0.39	3.55 ± 0.44	-5.2	< .001	0.62	Large improvement
Total	2.49 ± 0.40	3.48 ± 0.45	-5.3	< .001	0.63	Large improvement

Source: Z-values are derived from Wilcoxon signed-rank test; Effect size (r) = Z / √N (Cohen, 2013).

4.2.1 Descriptive Statistics

To evaluate the usability of the CT–DT module in enhancing learners' cognitive capacities, a one-group pretest–posttest design was employed with 35 primary students. Given the ordinal data, small sample size, and non-normal distribution (Ghasemi & Zahediasl, 2012), non-parametric methods were appropriately used for analysis.

Table 5 presents the descriptive statistics—including means (M) and standard deviations (SD)—for each measured construct (Critical Thinking, Creativity, and the overall composite score) at both pre- and post-intervention stages. All three constructs exhibited increased mean scores following the intervention. Specifically, students' critical thinking scores increased from M = 2.51 (SD = 0.42) to M = 3.42 (SD = 0.47), and creativity scores rose from M = 2.47 (SD = 0.39) to M = 3.55 (SD = 0.44). Similarly, the composite score improved from *M* = 2.49 (*SD* = 0.40) to *M* = 3.48 (*SD* = 0.45), indicating consistent gains across all measured dimensions.

4.2.2 Inferential Statistics

Wilcoxon Signed-Rank Tests were conducted to compare students' pre-testand post-intervention scores, given the ordinal nature of the data and the modest sample size (N = 35). This non-parametric method was appropriate for assessing within-group changes in perceived competencies. As shown in **Table 6**, statistically significant improvements were observed across all three measured dimensions—critical thinking, creativity, and overall self-efficacy—with p-values less than .001. The effect sizes (r = 0.60–0.63) indicate a significant practical impact, suggesting that the intervention produced meaningful cognitive gains.

4.2.3 Distributional Change

Descriptive visualisations (e.g., boxplots, see **Figure 6**) were used to explore distributional changes further. These revealed a noticeable rightward shift in post-intervention scores, reduced score dispersion, and fewer low-end outliers. This suggests average improvements and a convergence of performance gains across most participants.

No extreme outliers (>3 SD from the mean) were detected. Moreover, 95% of students improved at least one domain, and 68.6% demonstrated simultaneous gains in critical thinking and creativity. The average gain of 0.99 on a 5-point scale represents a 39.8% increase, further supporting the intervention's effectiveness.

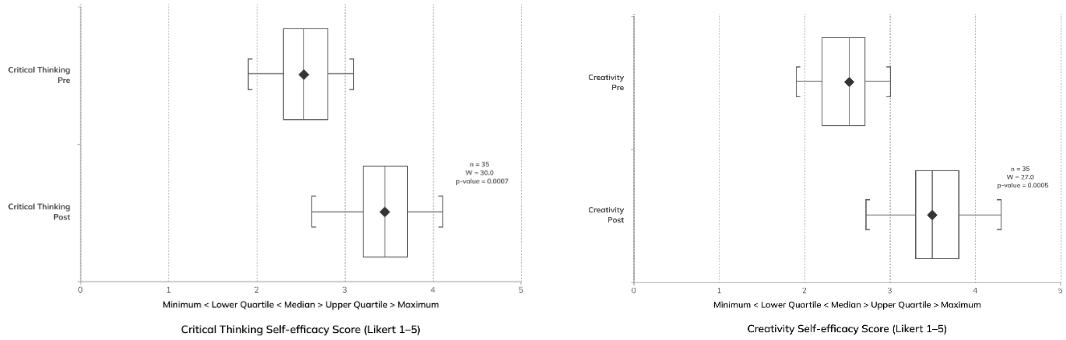


Figure 6: Boxplot representations of pre- and post-intervention scores for critical thinking and creativity (N = 35).

Overall, consistent withthe New World Kirkpatrick Model (Kirkpatrick & Kirkpatrick, 2016), Level 2 (Learning) assesses the degree to which learners acquire targeted knowledge and skills due to an instructional intervention. Anchored in constructivist theory and informed by integrated CT–DT pedagogical models (e.g., Brennan & Resnick, 2012), this study hypothesized that the intervention would enhance students' higher-order thinking skills (HOTS), particularly in critical thinking and creativity.

A single-group pretest–posttest design was implemented to evaluate this, and the Wilcoxon Signed-Rank Test was used for its suitability for small-sample, non-parametric data (Ghasemi & Zahediasl, 2012). The results revealed statistically significant improvements in both target domains, with Z-values of −5.0 (critical thinking) and −5.2 (creativity), respectively ($p < .001$). Large effect sizes ($r > 0.6$) suggest that the intervention yielded meaningful cognitive gains. These findings offer empirical support for the effectiveness of the CT–DT module in promoting 21st-century cognitive competencies.

The strong effect sizes underscore statistical and educational significance (Cohen, 2013). Kirkpatrick and Kirkpatrick (2016) argue that Level 2 should reflect not merely test score gains but also transformations in learners' capabilities. This study demonstrates that structured CT–DT engagement fosters cognitive transformation through iterative design and problem-solving. Pupils engaged in iterative problem-solving, collaborative project work, and reflective inquiry—practices widely recognised for enhancing cognitive growth. These findings are consistent with prior research (e.g., Lin et al., 2021; Wu et al., 2024), which has demonstrated that structured design tasks promote metacognitive development and foster both divergent and evaluative thinking (Ritchhart & Perkins, 2005; Sawyer, 2012, 2018, 2022).

From a deductive standpoint, the findings empirically support the theoretical assumption that structured, constructivist-oriented CT–DT tasks foster HOTS. The study confirmed that learners exhibited the anticipated growth by translating these expectations into measurable pre- and post-intervention outcomes. These results suggest the potential of integrated CT–DT pedagogy to develop 21st-century competencies in primary education. In summary, the findings provide empirical support for the theoretical proposition that integrating CT and DT enhances primary pupils' creativity and critical thinking, thus fulfilling instructional aims and aligning with Level 2 learning outcomes as defined in the NWKM framework.

5. Discussion

This study evaluated the feasibility and pedagogical impact of an integrated Computational Thinking–Design Thinking (CT–DT) module on fostering co-creation in primary school learners. Grounded in constructionist and social constructivist theory and analytically structured through the 4Cs framework and the New World Kirkpatrick Model (NWKM), this research operationalized co-creation through four interdependent competencies: communication, collaboration, critical thinking, and creativity. The findings demonstrate that these dimensions provide a theoretically coherent lens for understanding co-creation and yield measurable outcomes in both behavioral engagement and cognitive skill development.

5.1 RQ1: How is the feasibility of the CT–DT module demonstrated through communication and collaboration among primary school pupils, based on Level 1 (Reaction) of the New World Kirkpatrick Evaluation Model?

These results highlight the potential of an integrated CT–DT pedagogy to foster 21st-century competencies in primary education. In summary, the findings provide empirical support for the theoretical proposition that integrating CT and DT enhances primary pupils' creativity and critical thinking, thus fulfilling instructional aims and aligning with Level 2 learning outcomes as defined in the NWKM framework.

The analysis of classroom observations revealed a clear, progressive shift in student behaviour—from teacher-dependent interactions in the early modules to self-directed, peer-regulated engagement by the midpoint and final sessions. Students collaboratively framed problems, iteratively generated ideas, provided feedback, and regulated task execution in ways consistent with design-based learning and co-constructivist models.

Communication and collaboration, as conceptualized within the 4Cs, served as observable markers of co-creation at Kirkpatrick Level 1 (Reaction). For instance, behaviours such as dialogic meaning-making and distributed ideation reflect not only surface-level engagement but also the epistemic processes that underpin shared knowledge construction. The increased frequency of student-led coordination and co-design by Modules 4–6 underscores the feasibility of introducing complex design-thinking routines at the primary level when supported by structured CT–DT pedagogies.

These findings validate the theoretical claim that co-creation is not an abstract ideal, but a process that can be intentionally fostered, observed, and measured through contextually grounded indicators. The data suggest that communication and collaboration—when scaffolded through iterative, real-world problem solving—enable young learners to act as epistemic agents within authentic learning communities.

5.2 RQ2: What is the effect of the CT–DT module on fostering critical thinking and creativity among primary school pupils, as assessed through Level 2 (Learning) indicators of the New World Kirkpatrick Evaluation Model?

Quantitative analysis using the LIS-SES indicated statistically significant gains in students' self-reported creativity and critical thinking. These improvements, assessed through Wilcoxon signed-rank tests, were accompanied by large effect sizes ($r > 0.6$), providing robust evidence for the learning impact of the CT–DT module.

Creativity and critical thinking, as defined within the 4Cs, which correspond to Kirkpatrick Level 2 (Learning) and serve as proxies for students' cognitive engagement with ill-structured, interdisciplinary tasks. These competencies were intentionally embedded into each instructional module: students iterated designs, evaluated alternatives, abstracted problems, and considered user needs—behaviors that reflect dual-process thinking and transdisciplinary problem-solving.

Notably, the convergence of behavioural and cognitive outcomes supports the proposition that co-creation is both a social and intellectual process that develops through authentic participation in problem-centred, collaborative learning environments. The module's effectiveness in fostering measurable growth in both domains suggests that co-creation is feasible at the primary level and can be cultivated systematically through intentional instructional design.

6. Conclusion

The successful implementation and evaluation of the CT–DT module provide compelling evidence of its pedagogical effectiveness in fostering students' 4Cs within a real-world classroom context. Specifically, this study concludes that integrating a CT-DT module into Chinese primary school classrooms is pedagogically feasible and educationally valuable. The intervention significantly improved students' 4C competencies, with the most substantial gains occurring in students' capacity for co-creation. The findings suggest that structured CT–DT learning experiences meaningfully support co-creation processes among primary school students. Furthermore, mixed-methods evaluation, including classroom observation and self-efficacy assessment, offers compelling empirical evidence substantiating the module's instructional impact. These findings extend the growing body of literature on 21st-century learning and CT–DT pedagogies.

However, these findings are interpreted considering several limitations. First, the study involved a relatively small sample from a single primary school, limiting the generalisability of the results. Variation in pupils' prior knowledge and inconsistencies in instructional emphasis across sessions influenced the reliability of the learning outcomes. Furthermore, the study focused on short-term outcomes corresponding to the first two levels of the NWKM framework. Capturing longer-term impacts and higher-order learning gains require longitudinal research designs. In addition, quasi-experimental methodologies enhance internal validity and provide more robust causal inference than designs based solely on classroom observation and pre/post-test comparisons.

Notably, this study moves beyond a surface-level examination of the relationship between CT and DT, seeking instead to elucidate how their integration—when situated within a PjBL environments supports co-creation and co-design processes among primary school students. By integrating CT and DT within a PjBL setting, this study found that primary students demonstrated increased engagement, particularly in collaboration and communication, and cultivated critical thinking and creativity skills. From an intervention perspective, the structured CT–DT module offered developmentally appropriate scaffolds that supported idea generation, iterative prototyping, and the articulation of solutions. By applying CT principles (e.g., decomposition, abstraction) to DT-driven activities (e.g., empathy mapping, prototyping), pedagogical elements such as peer dialogue and reflective discourse (which also facilitate metacognitive development) were effectively activated. By embedding these strategies into authentic, real-world tasks, students were enabled to navigate between divergent and convergent thinking fluidly. In conclusion, the study contributes to classroom practice by evidencing the educational value of integrating CT and DT to foster 4C skills among primary learners. Regarding theoretical advancements, previous research has established links between CT-DT module and enhanced learning outcomes across both analytical and creative domains, which our findings further corroborate.

In conclusion, the study results expand the practical application of integrated CT and DT in primary school classrooms, particularly in promoting deeper engagement with 21st-century skills such as creativity, collaboration, critical thinking, and communication. Previous studies have demonstrated the relationship between CT and DT regarding theoretical advancements. This study's findings revealed that applying CT and DT within a PjBL framework effectively strengths 4C skills among primary school pupils. Moreover, these insights offer actionable guidance for educators and instructional designers in developing interdisciplinary, child-centred curricula within authentic learning environments. To deepen young learners' understanding and promote reflective thinking, this study recommends that instructors incorporate scaffolding strategies or intrinsic supports to facilitate inquiry-based exploration. Specifically, when designing CT–DT integrated activities, educators are encouraged to utilize tools such as design journals, visual thinking templates, and peer feedback protocols to promote metacognitive awareness and structured collaborative dialogue. In short, the CT–DT module has the potential to facilitate co-creation by cultivating 4C competencies among primary school pupils and enriches the experiences of their learning journey.

Credit authorship contribution statement

Zhuoya Bao: review & editing, Writing – original draft, Validation, Methodology, Investigation, Formal analysis, Data curation, Conceptualization.
Saedah Binti Siraja and Siti Hajar Halili: review & editing, supervision & feedback–original draft.

Data availability

The authors do not have permission to share data.

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Conflict of Interest Statement

The authors declare that there is no conflict of interest regarding the publication of this study.

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