The Four-Component Instructional Design (4C/ID) Model in Higher Education: A Systematic Literature Review

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Abstract

Complex skills development in higher education is constrained by fragmented instruction, limited support for whole-task learning and increased cognitive load in online and blended formats. The four-component instructional design (4C/ID) model has been proposed as a task-centred approach designed to address these challenges. This systematic review synthesises empirical applications of 4C/ID in higher education over the past three decades. Following PRISMA 2020, searches of six major databases covered January 1992 to 7 December 2025. Fourteen empirical studies met the inclusion criteria and were appraised using the Mixed Methods Appraisal Tool. Most were quasi-experimental (n = 10), with two mixed-methods and two pre–post studies; the pooled sample comprised 1,109 students. Research clustered in Asia and North America across education and educational technology, health and computing, with a few studies in language and architecture. Across studies, implementations emphasised whole-task sequencing, scaffold fading and coordinated supportive and procedural information, often supported by digital technologies. Evidence indicates consistent gains in performance and transfer outcomes. Well-sequenced guidance reduced extraneous load and supported germane processing, though intrinsic load was higher early in whole-task learning. Common limitations included small samples, non-random allocation and limited follow-up. Overall, 4C/ID shows promise for improving learning outcomes in higher education. Future work should broaden samples and contexts, strengthen designs, standardise outcome measures and report implementation fidelity to advance both research and practice.

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Practitioner Notes

1. Organise instruction around whole-task sequences anchored in authentic problems; align practice and assessment to the same tasks.
2. Plan scaffold fading across tasks (not just within a single session); use brief effort checks to tune task complexity and guidance.
3. Pair supportive information (concepts and strategies) with procedural information (just-in-time steps); keep each aid concise (≤1 page).
4. Integrate digital supports (e.g., simulations, computer-supported formative checks, virtual fieldwork) to provide timely feedback and additional practice.
5. Evaluate performance and transfer with criterion-aligned rubrics, and document implementation fidelity (what, to whom, how often).

Keywords

Four-component instructional design (4C/ID); higher education; complex learning; cognitive load

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Introduction

Against the backdrop of competency-based and outcomes-oriented approaches becoming central to higher education reform, university classrooms face several implementation challenges. On the one hand, constructive alignment requires that teaching and assessment be organised around intended learning outcomes, yet actual teaching often remains fragmented, which undermines integrated learning and transfer (Biggs & Tang, 2022; Frerejean et al., 2019; van Merriënboer et al., 2019). On the other hand, large class sizes and tight semester schedules make it difficult to organise whole-task activities, provide scaffolding, and deliver timely feedback, even though high-quality feedback is one of the most powerful influences on learning (Carless & Boud, 2018; Hattie & Timperley, 2007). Meanwhile, the proliferation of online and blended learning increases information-processing demands and coordination costs; without careful design, learners may experience cognitive-load imbalances that hinder the formation and transfer of complex skills (Bernard et al., 2014; Means et al., 2013; Sweller et al., 2011). Collectively, these practical challenges point to a core need: a teaching-design framework that tightly integrates learning–doing–assessment around authentic tasks to enhance the transferability and applicability of learning.

Evidence favours guided, structured approaches over minimally guided ones for complex learning, especially for novices (Kirschner et al., 2006). Similar patterns are seen with active learning structures across class sizes in STEM disciplines (Freeman et al., 2014). These findings suggest that instructional approaches that combine authentic whole-task learning with sequenced support, scaffolding and timely feedback may better address the practical challenges faced in university classrooms. The need for such approaches is particularly salient where complex skills, integration across domains, and cognitive load considerations intersect with large cohorts and varied teaching modalities.

The four-components instructional design (4C/ID) instructional design model centres on whole-task learning, supplemented by supporting information, procedural information, and partial-task practice. Through task sequencing and progressive fading, it holds promise for addressing the challenges outlined above (Bruner, 1966; Kirschner et al., 2018; Merrill, 2002; Van Merriënboer, 1997). Existing research indicates that 4C/ID has yielded positive outcomes in vocational education, medical education, and K-12 settings, effectively promoting the acquisition and transfer of complex skills. However, empirical evidence remains insufficient in higher education compared to these domains.

More critically, higher education is characterised by greater learner autonomy, higher cognitive demands, more prevalent interdisciplinary integration, and more complex class sizes and teaching modalities. These contextual differences may significantly influence the implementation methods and effectiveness boundaries of 4C/ID, leaving its adaptability and efficacy in university classrooms unclear (Van Merriënboer et al., 2019). Given these contextual considerations and the limited synthesis of empirical findings, a systematic review of 4C/ID applications in higher education is needed to understand how the model has been implemented, under what conditions it has been applied, and what outcomes have been achieved. Based on this gap, this study focuses on the higher education context and poses two primary research questions:

Research Question 1. What common practices and variations exist in the pedagogical implementation and technological integration of 4C/ID within higher education?

Research Question 2. What do existing empirical studies reveal about the effectiveness of 4C/ID in higher education?

To address these questions, this study systematically reviews recent empirical research to provide evidence-based insights into the practical challenges of university teaching. It aims to provide actionable design principles and technology integration strategies for university faculty and instructional designers. Based on a comprehensive quality assessment, it clarifies the applicability boundaries of 4C/ID in higher education and identifies future research directions.

Literature

The Four-Component Instructional Design Model (4C/ID)

Since the 1990s, instructional design in higher education has shifted from goal-oriented prescriptions to task-centred approaches. This shift reflects a growing consensus that fragmented knowledge transmission is ill-suited to developing the integrated, complex skills required in occupational settings (Frerejean et al., 2019; van Merriënboer et al., 2019). Rather than targeting narrowly defined objectives, task-centred design asks learners to tackle authentic situations, thereby supporting deeper transfer.

The 4C/ID model proposed by van Merriënboer (1992) typifies this paradigm. It offers a structured framework for professional competence development via authentic tasks and scaffolded support. The model comprises four interrelated components: (1) learning tasks that mirror real work contexts; (2) supportive information that enables conceptual understanding and cognitive strategies; (3) procedural information for routine elements; and (4) part-task practice to automate subskills through repetition (van Merriënboer et al., 2003; Kirschner et al., 2018). The value of 4C/ID lies in its emphasis on holistic task learning—acquiring skills in complete contexts rather than in isolation. As task complexity increases, fading of guidance fosters learner autonomy and adaptive expertise. Consistent with cognitive load theory, appropriate sequencing and fading can reduce extraneous load and facilitate germane processing, contributing to enduring schema construction (Sweller et al., 2011).

4C/ID Model in Educational Context

Empirical studies report implementations of the 4C/ID model in domains that require integrated practical competence, including clinical medical education, teacher preparation, and vocational–technical fields such as robotics and design (Schoenmakers et al., 2025; Rhodes et al., 2024; Xu et al., 2024). Adaptations to immersive technologies—for example, virtual simulation—further illustrate the model's applicability to diverse delivery formats (Guerrero & Bautista-Rojas, 2024). Evidence of effectiveness has also been documented in medical education, teacher training, computer science, and vocational education (Xu et al., 2024).

At the same time, full-fidelity implementation demands fine-grained design decisions (e.g., task sequencing, the pacing of guidance fading, and assessment alignment), which can be challenging under tight schedules or content-heavy courses. Questions also remain about the model's adaptability across learner groups, digital learning environments, and multicultural systems. In higher education specifically, the evidence base is still limited: many studies are single-discipline cases or small-scale pilots, and much of the literature foregrounds principle explication over rigorous outcome evaluation (e.g., Mun & Jo, 2025; Lwin et al., 2024). This makes it difficult for instructors to judge effects on learning outcomes and on the development of complex competences. Guided by these gaps, the present review synthesizes empirical studies of 4C/ID in higher education to clarify (a) research characteristics, (b) instructional implementation—including technology integration, and (c) outcomes. In line with our research questions and subsequent reporting, outcomes are considered across learning results/teaching effectiveness and cognitive load.

Method

Search Strategy

This review employed a structured and transparent search strategy across six core academic databases: Web of Science, Scopus, ERIC, ProQuest, IEEE Xplore, and Google Scholar. Searches were limited to titles and abstracts where supported. Boolean operators and truncation were applied to balance precision and recall. For transparency, a typical search string was:

> (“4C/ID” OR “four-component instructional design” OR “4C-ID” OR 4CID) AND (“higher education” OR universit* OR college*)

Truncation (e.g., universit* to capture university/universities) and model synonyms (e.g., “4C-ID”, “4CID”) were included to cover spelling variants and related terminology. The search period covered publications from January 1992 (when the 4C/ID model was first introduced) to 7 December 2025. Only peer-reviewed journal articles were retained for initial screening. Automated and manual de-duplication were used to maximise accuracy and transparency. The search and screening procedures adhered to PRISMA 2020 guidelines (Page et al., 2021); the PRISMA flow diagram is reported in Section 4.1. In addition, this review followed widely accepted best-practice recommendations for systematic reviews, emphasising alignment between research questions and review objectives, transparency of the search strategy, systematic screening and selection, quality appraisal, and contributions that extend beyond descriptive synthesis.

Inclusion Criteria

Inclusion and exclusion criteria were developed with reference to the PICO framework (Population, Intervention, Comparison, Outcomes) and the PRISMA-ScR guidance to ensure that the selected literature aligned with the core objective—assessing the effectiveness of empirical applications of the 4C/ID model in higher education. Criteria covered instructional design fidelity, research design characteristics, outcome indicators, participant population, and topical relevance. A structured summary is provided in Table 1. Reference management was conducted in EndNote 21 for citation organiation and de-duplication. Dual independent screening was performed at title/abstract and full-text stages. Disagreements were resolved by discussion, and inter-rater agreement was assessed using Cohen’s κ (threshold set at 0.85), ensuring reproducibility of screening decisions and credibility of inclusion.

Table 1

Inclusion and Exclusion Criteria

Category	Inclusion Criteria	Exclusion Criteria
Instructional Design	Fully implements all four 4C/ID core components. Instructional materials must undergo content validity verification	Partial implementation of the 4C/ID model Studies that do not adapt the model based on Jeroen Van Merriënboer's original theoretical framework.
Study Design	Uses causal relationship verification designs. For mixed-methods research, the study must describe the triangulation mechanism for qualitative and quantitative data.	Purely descriptive studies. Studies relying on self-reported data for more than 50% of outcome measurements.
Outcome Measurement	Must include objective, performance-based indicators.	Fails to distinguish declarative knowledge and procedural skills in outcome variables.
Participants	Target population must be formally enrolled students in higher education.	Studies involving continuing education learners and teacher professional development programs.
Research Focus	The study must clearly investigate how the 4C/ID model affects learning outcomes.	The study does not focus on the impact of the 4C/ID model or lacks a comparative analysis.
Literature Type	Must be peer-reviewed and published in English or Chinese.	Conference abstracts, theoretical discussion papers, and unpublished theses or dissertations. Non-English/Chinese literature

Quality assessment

To evaluate methodological rigor, we adopted the Mixed Methods Appraisal Tool (MMAT), applicable to both qualitative and quantitative components of empirical studies (Hong et al., 2018; Pace et al., 2012). Two reviewers independently appraised each study using a standardised form aligned with the MMAT criteria (e.g., clarity of research questions, appropriateness of design, sampling and data collection procedures, measurement validity, and, where relevant, integration of methods). Prior to full screening, the reviewers calibrated their judgments on a pilot set. Discrepancies were resolved by discussion until consensus; when needed, a third reviewer was available for adjudication. Inter-rater agreement was quantified using Cohen's κ (agreement threshold set at 0.85), with the coefficient reported in Section 4.2. Following MMAT guidance, we did not compute an overall summary score; instead, we report criterion-level judgments and study counts to preserve transparency. The aggregate quality assessment results (common strengths and limitations across studies) are presented in Section 4.2, thereby avoiding the mixing of methods and results.

Extraction

A standardised data extraction form was designed to ensure consistency and comparability across studies. The following information was captured for each included study: author and year, publication type, sample size (N), participant characteristics (e.g., age and level, when available), duration of intervention, disciplinary field, country/region of implementation, study design (e.g., quasi-experimental, RCT, mixed methods), details of experimental and comparison groups (if any), key 4C/ID implementation features, and primary outcomes/measures. Two reviewers extracted data independently; disagreements were resolved through discussion to minimise subjective bias. Extracted data were summarised using descriptive statistics and tabular presentation of study characteristics. Where feasible, outcome categories were harmonised (e.g., performance-based learning outcomes, transfer, cognitive load/process measures) to support cross-study synthesis consistent with the review questions. All extracted entries were double-checked for accuracy and internal consistency prior to analysis.

Analysis

Extracted data were analysed using a structured narrative approach. A comparative matrix was used to organise implementation features, outcome indicators and study characteristics. Two reviewers independently coded the extracted information and inductively grouped similar findings into higher-order categories aligned with the review questions. Recurring design patterns (e.g., whole-task sequencing, scaffold fading, supportive and procedural information) informed formation of the implementation and outcome themes reported in Section 4. Frequency counts were used to summarise the distribution of design choices and outcomes across studies. MMAT appraisal findings contextualised interpretation of effectiveness claims. Coding discrepancies were resolved through discussion until consensus.

Results

Study Selection (PRISMA)

This study adhered to PRISMA 2020. Records were identified in Web of Science, Scopus, ERIC, ProQuest, IEEE Xplore, and Google Scholar from 1992 to 7 December 2025, yielding 248 hits. After removal of 54 duplicates, 194 titles and abstracts were screened against a priori criteria. Exclusions at this stage reflected topical irrelevance, lack of substantive implementation of all four 4C/ID components, or absence of content-validity evidence for instructional materials; studies primarily reliant on self-report outcomes (>50%) or employing purely descriptive designs were also excluded. Thirty full texts were assessed; 3 were not retrievable despite reasonable attempts, and 13 were excluded for one or more of the following reasons: not an empirical effectiveness study; insufficient alignment with the full 4C/ID framework; no objective/performance outcomes or no distinction between declarative and procedural measures; participants not enrolled higher-education students; or, for mixed-methods studies, no description of triangulation/integration. Only peer-reviewed English/Chinese publications were retained (conference abstracts, theoretical papers, and theses/dissertations excluded). In total, 14 studies met all criteria and were included (Figure 1 and Table 2).

Figure 1

PRISMA 2020 flow diagram for study selection (Jan 1992–7 Dec 2025; counts include the April–December 2025 top-up search).

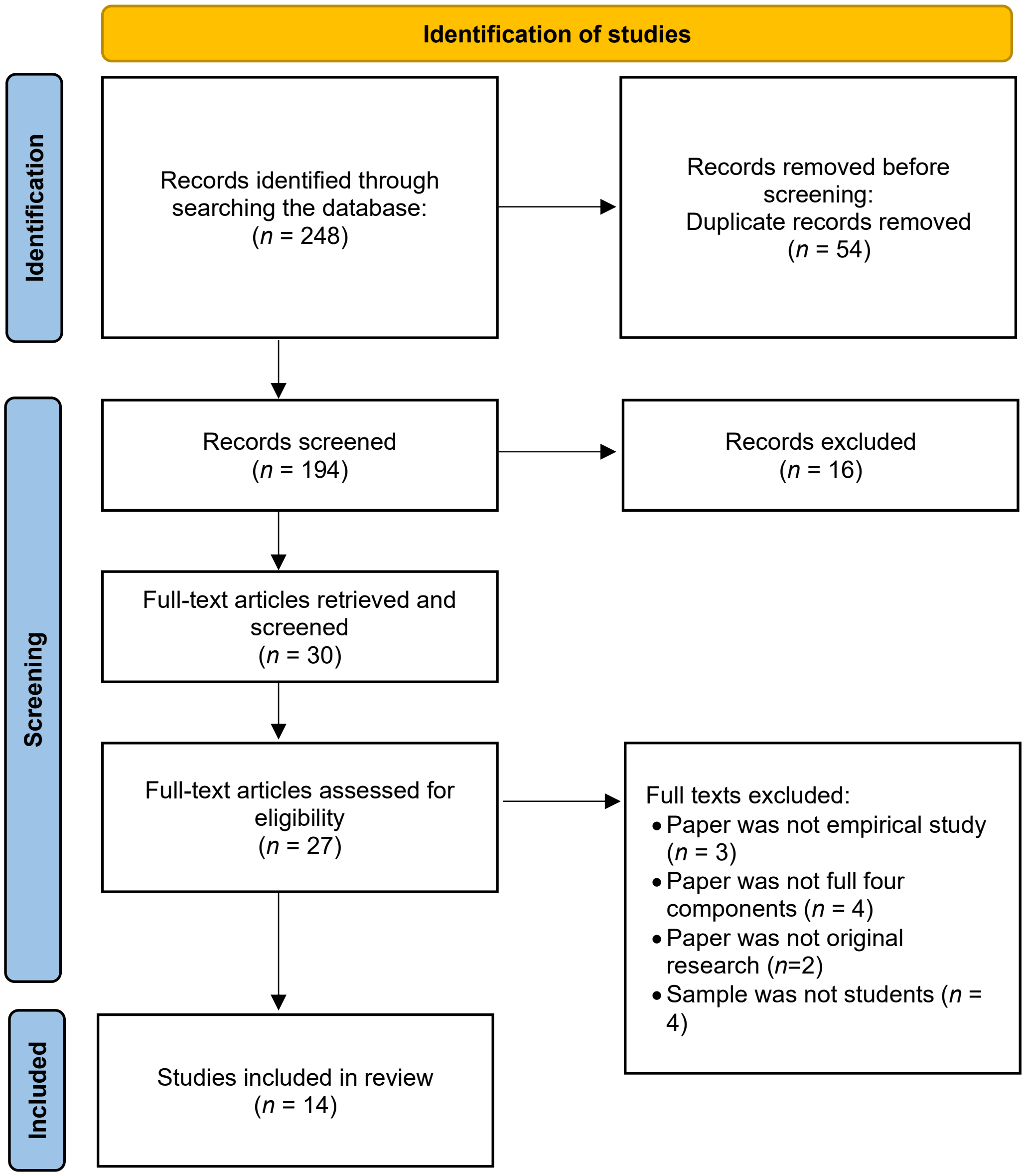

Table 2

Characteristics of included studies

Author (Year)	Sample Size	Duration	Field	Country	Design	Intervention	Outcome
Akkaya & Akpinar (2022)	61	-	Computer Science	Turkey	Quasi-experimental	Game-based 4C/ID programming	Improved subject knowledge and computing skills
Argelagós et al. (2022)	80	2 months (60 hours)	Education	Spain, Colombia, others	Quasi-experimental	EG: Task-centered instruction (4C/ID), CG: Traditional method	EG improved problem solving vs. CG
Choi, Kim & Song (2024)	34	5 weeks	Education	South Korea	Quasi-experimental	EG: Emphasis + Simplifying (4C/ID), CG: Emphasis only	EG had better cognitive strategies and structure building
Dawkins et al. (2024)	85	2 semesters	Medicine	USA	Quasi-experimental	Cohort A: Clinical US, Cohort B: Educational US	All scores improved post-course; higher confidence and skills
Divon & Ghosal (2024)	25	5 days	Education/Field Research	Norway	Mixed methods	4C/ID with virtual field course and project work	Achieved intercultural goals, managed cognitive load well
Kolcu et al. (2020)	26	21 days	Dentistry	Turkey	Non-experimental (single group pre-post)	Distance dental education procedure training	Improved psychomotor skills
Lebedintseva et al. (2024)	25	9 months	Language	Uzbekistan	Quasi-experimental	EG: 4C/ID for language, CG: Traditional method	EG had better writing, engagement, and satisfaction

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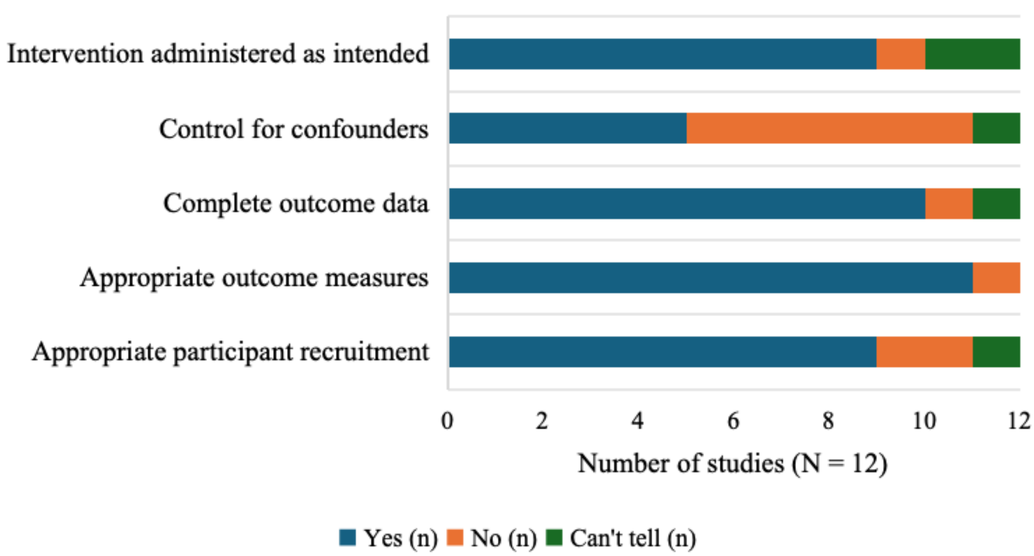
Author (Year)	Sample Size	Duration	Field	Country	Design	Intervention	Outcome
Lim, Reiser & Olina (2009)	51	1 day (2×60min)	Computer Science	USA	Quasi-experimental	EG: Whole-task design, CG: Part-task	EG developed more complex skills
Peng et al. (2022)	69	6 weeks	Computer Science	China (South)	Non-experimental (single group pre-post)	Project-based computing (no CG)	Improved knowledge and project outcomes
Pontes Miranda & Celani (2018)	65	1 semester	Architecture	Brazil, Portugal	Experimental	EG: Algorithm-Aided Design (4C/ID), CG: Conventional design	EG outperformed CG in knowledge and product quality
Postma & White (2016)	412	3years	Dentistry	South Africa	Quasi-experimental	EG: Case-based teaching, CG: Lecture-based	EG had better diagnostic accuracy, clinical decisions, and performance
Xu et al. (2024)	54	14 sessions (90 mins each)	Vocational Training	China	Quasi-experimental	EG: 4C/ID + computer-supported assessment, CG: Traditional	EG enhanced schema, transfer, satisfaction; no harm to motivation
Yan et al. (2012)	74	6 weeks (1 semester)	Educational Technology	China	Mixed methods	EG: 4C/ID micro e-learning, CG: Traditional instruction	Micro learning improved engagement and transfer
Zamharir, Karami, Jamali, & Rezvani (2025)	48	4 sessions × 90 minutes	Educational Evaluation	Iran	Quasi-experimental	EG: 4C/ID—class + real-work tasks; fading support. CG: 4C/ID—class + simulated tasks; fading support.	EG significantly outperformed CG on learning achievement; design-thinking mindset mproved significantly

Quality Assessment Results

MMAT appraisal showed generally strong implementation fidelity and outcome reporting among the twelve quantitative non-randomised studies included in this review. Most studies clearly described participant recruitment procedures and reported complete outcome data, and three-quarters demonstrated intervention delivery as intended (Figure 2). In contrast, control for confounders was limited in most cases, with only five studies explicitly accounting for confounding variables through design or statistical adjustment. This restricts the strength of any causal claims drawn from reported effects. The two mixed-methods studies met all four MMAT mixed-methods criteria: both provided a clear rationale for adopting a mixed-methods design, integrated qualitative and quantitative components appropriately, and interpreted the integrated results consistently. However, one study did not report sufficient detail to assess the methodological rigour of each component independently. Taken together, the evidence base displays reasonable reporting integrity and appropriate use of outcome measures, but the absence of randomisation and limited control for confounding remain key methodological limitations in current 4C/ID studies in higher education.

Figure 2

MMAT criterion-level frequencies for quantitative non-randomised studies (N = 12).



Characteristics of the Included Studies

This study included 14 empirical investigations focusing on the application of the 4C/ID model in higher education contexts, spanning multiple countries and disciplinary fields. The findings collectively demonstrate a cross-contextual and cross-disciplinary distribution pattern (Table 2).

From a geographical perspective, the research exhibits a “broad yet uneven” distribution: China produced the highest number of studies (3), followed by the United States and Turkey with 2 each. The remaining studies originated from Iran, South Korea, Norway, Uzbekistan, South Africa, and multi-country collaborations such as Spain/Colombia and Brazil/Portugal. Overall, Asian countries and some Middle Eastern/African nations demonstrate higher levels of engagement with 4C/ID, while Western Europe and Latin America show relatively low publication volumes on this topic. This disparity may be linked to regional educational priorities, research funding structures, and the level of awareness and dissemination of 4C/ID concepts.

Regarding research methods and samples, the predominant design type was quantitative non-randomised research (quasi-experimental/experimental-like) (approximately 10/14). Additionally, there were 2/14 non-experimental pre-post studies and 2/14 mixed-method studies. No reports of formal random assignment or statistical power analysis were identified. Most studies clearly described intervention and evaluation procedures, with commonly used tools including pre-post questionnaires, performance tasks, and observational records. Sample sizes varied considerably (25–412 participants), totalling 1,109 enrolled college students. Most studies involved 30–85 participants, with a rough average of about 79 participants. Intervention durations ranged from short-term intensive sessions (several days/single full day) to one semester or longer, demonstrating the 4C/ID approach's applicability across different course formats.

In terms of disciplinary fields, the majority of included studies focused on education/educational technology (approximately 6/14), followed by medical/dental education and computer science (each accounting for about 3/14). Additionally, scattered cases emerged in language learning and architecture/design. Overall, the application of 4C/ID has spanned multiple disciplines, though it remains predominantly concentrated in education, medicine, and digital skills development.

Whole-Task Sequencing with Scaffold Fading as a Transferable Implementation Model

The included studies demonstrated high consistency at the implementation level: most interventions centered on a whole-task sequence, integrating four key elements—learning tasks, supportive information, procedural information, and partial practice—while progressively reducing scaffolding and providing timely feedback as task complexity increased (Lim, Reiser & Olina, 2009; Choi, Kim & Song, 2024). Within this framework, 4C/ID maintains stable implementation across face-to-face, online, or blended teaching settings (Argelagós et al., 2022; Xu et al., 2024).

From the perspective of task and scenario design, common approaches include: First, case/scenario-driven—advancing diagnosis, decision-making, and strategy transfer through real-world cases or professional scenarios (Dawkins et al., 2024; Postma & White, 2016; Pontes Miranda & Celani, 2018). Second, project/problem-driven—organising task clusters around deliverables or complex problems, emphasising strategy selection, reflection, and framework development (Peng et al., 2022; Choi, Kim & Song, 2024). Third, dual real-world/simulation contexts—completing core task frameworks in class while extending practice and transfer reach through real workplaces or high-fidelity simulations outside class (Kolcu et al., 2020). Recent comparative evidence further indicates that embedding the whole-task sequence within authentic workplace environments yields stronger gains in design thinking and learning outcomes than simulated environments, reinforcing the value of dual-context integration in 4C/ID implementation (Lebedinets, Kagata, Mazalova, Samokhina, & Chugreev, 2024; Zamharir, Karami, Jamali & Rezvani, 2025). Fourth, microlearning/microtask embedding—integrating granular procedural practice into holistic task flows to balance pacing and automation requirements (Yan et al., 2012).

Regarding technology integration, the study emphasises “using technology to serve complex tasks” rather than technology for technology's sake: virtual simulation and remote fieldwork are employed to construct highly realistic scenarios and low-risk practice pathways (Divon & Ghosal, 2024); Computer-supported formative assessment/learning analytics are employed for process tracking, immediate feedback, and visualising progress, supporting scaffolding reduction and schema construction (Xu et al., 2024); gamification and interactive tasks deliver procedural knowledge and partial practice, enhancing practice density and engagement (Akkaya & Akpinar, 2022). Furthermore, 4C/ID has been applied to non-traditional STEM contexts such as language and intercultural education, supporting composite competencies like writing, communication, and engagement through task sequencing and scaffolding management (Divon & Ghosal, 2024).

Regarding implementation feasibility and safeguards, multiple studies indicate that curriculum team support, reusable resources, and stable platforms are critical for enhancing implementation fidelity and sustainability. Factors such as large class sizes, semester duration, and physical accessibility influence the granularity of task sequences and the pace of scaffolding removal (Kolcu et al., 2020). Overall, 4C/ID demonstrates a transferable structured model across disciplines and lesson types: using holistic tasks as the framework, employing the four elements and decreasing scaffolding as mechanisms, leveraging technology as an enhancer for contextual enrichment and process management, and achieving the learning objective of “learning to do” through the integration and transfer of complex skills in real or near-real contexts.

Performance and Transfer Gains Enabled by Scaffolded Whole-Task Learning

A synthesis of 14 included studies indicates that 4C/ID demonstrates overall positive teaching outcomes in higher education settings. Most research reports advantages in performance-based task scores, knowledge integration, and cross-context transfer across multidisciplinary scenarios including computer science and educational technology, medicine/dentistry, architecture, and languages (Akkaya & Akpinar, 2022; Lebedinets et al., 2024; Lim, Reiser & Olina, 2009; Postma & White, 2016; Xu et al., 2024). Under conditions featuring holistic tasks as the framework, supplemented with supportive/procedural information and partial practice, and implementing scaffolded reduction, experimental groups generally demonstrated superior task completion quality, strategy application, and subsequent transfer compared to control groups or pre-tests. This pattern aligns with evidence showing that whole-task learning situated in real work environments leads to greater improvements in higher-order competencies such as design thinking compared with simulated settings (Zamharir, Karami, Jamali & Rezvani, 2025).

Beyond cognitive and skill-based outcomes, several studies have also reported improvements in non-cognitive outcomes such as learning engagement, satisfaction, self-efficacy, and learning commitment (Argelagós et al., 2022; Yan et al., 2012). These findings align with the “learning by doing in complete contexts” emphasised by 4C/ID: when learning tasks are connected to real or near-real contexts and supported by explicit scaffolding and feedback, learners are more likely to develop positive experiences and sustained engagement.

Regarding cognitive load, multiple studies support the effective regulation of load by the 4C/ID framework. For instance, under conditions of computer-supported formative assessment and immediate feedback, learning performance improved without significant additional burden, suggesting that external load was controlled while beneficial learning-related load was utilised (Xu et al., 2024; Divon & Ghosal, 2024). It is important to note that the overall task sequence may induce higher intrinsic load in its early stages (Lim, Reiser, & Olina, 2009). However, through task sequence optimisation, scaffold reduction, and the integration of reflection time, this load can be channeled toward schema construction and distant transfer, ultimately manifesting as performance advantages in subsequent tasks.

Consistent with the results of the Methodological Quality Assessment Tool (MMAT), most studies in this review demonstrated adequate recruitment, measurement validity, and outcome completeness. However, the implementation of confounding factor control and randomisation was limited, thereby constraining the strength of causal inference. Overall, the existing evidence is directionally consistent and spans diverse disciplines, supporting the potential of 4C/ID to promote the acquisition and transfer of complex skills in higher education. Its effectiveness aligns with the proposed mechanism and model assumptions (whole-task approach + scaffolded reduction + timely feedback and assessment). However, more rigorous research designs are needed to further validate the robustness and external validity of these conclusions.

Discussion

Characteristics of the Included Studies

This review included 14 empirical studies on 4C/ID in higher education contexts, revealing a pattern characterised by "broad geographical coverage with uneven distribution, diverse yet relatively concentrated disciplines, and predominantly non-randomised designs." Geographically, studies spanned multiple countries and transnational collaborations across Asia, Europe, North America, and Latin America. Disciplinary focus was highest in education/educational technology, medicine/dentistry, and computer-related fields, with additional cases in language studies and architecture/design. Methodologically, quantitative non-randomised designs predominated, supplemented by a few mixed-methods studies providing process evidence. Sample sizes ranged from 25 to 412 participants, with intervention durations varying from short-term intensive sessions to one semester or longer. Quality assessment revealed generally adequate measurement tool appropriateness and outcome data completeness, but weaker control of confounders and randomisation (Table 2; Figure 2). This indicates that while the current evidence demonstrates considerable breadth and consistency, the strength of inferences remains constrained by study design limitations.

Implementation Approaches

The included studies exhibit high commonality and transferability at the implementation level. Most adopt an overall task sequence as their framework, systematically integrating the four elements (learning tasks, supportive information, procedural information, and partial practice). They progressively reduce scaffolding and provide timely feedback as task complexity increases. Common task and scenario paradigms include case/scenario-driven, project/problem-driven, real-simulation dual contexts, and microtask embedding. Technology integration is oriented toward serving complex tasks, commonly employing virtual simulation/remote fieldwork, computer-supported formative assessment, and gamified/interactive tasks (Section 4.4). These models align with the mechanism assumptions of 4C/ID, providing replicable pathways for interdisciplinary implementation.

Application Outcomes

Comprehensive evidence indicates that 4C/ID generally yields positive learning outcomes across multidisciplinary settings: improvements are observed in the quality of performance-based tasks, knowledge integration, and cross-contextual transfer. Non-cognitive outcomes such as engagement, satisfaction, and self-efficacy also show enhancement. Regarding cognitive load, while higher intrinsic load may occur in the early stages of overall tasks, optimised task sequencing, gradual scaffolding reduction, and timely feedback help control extrinsic load and activate beneficial learning-related load. This supports schema construction and subsequent transfer. Thus, the current findings align positively with the “overall task-scaffolding-feedback” mechanism proposed by 4C/ID. However, due to limitations in research design rigor, the strength of causality requires further validation in subsequent studies.

Theoretical and Practical Implications

The integrated findings of this review align with the core mechanisms of 4C/ID: organising tasks into holistic sequences, providing supporting information, procedural guidance, and partial practice, while implementing gradual scaffolding reduction and immediate feedback as task complexity increases (van Merriënboer & Kirschner, 2017; Merrill, 2002). This facilitates the transition from “completing tasks within a context” to “constructing transferable schemata.” (Sweller, Ayres & Kalyuga, 2011). In terms of cognitive processing, this pathway helps reduce extraneous cognitive load unrelated to learning to manageable levels (Kirschner, Sweller & Clark, 2006). It channels learners' resources toward beneficial cognitive load associated with learning—such as strategising, structuring, and reflective integration—while simultaneously accommodating and “domesticating” the initially high intrinsic cognitive load of complex tasks (Sweller, Ayres & Kalyuga, 2011). Within the framework of sequenced, layered tasks and feedback mechanisms, this load transforms into a driving force for schema construction and long-term transfer. Thus, 4C/ID not only promotes “getting the task done” but also builds a structured bridge between high-authenticity tasks and manageable cognitive load (Freeman et al., 2014; Hattie & Timperley, 2007). This explains the performance gains and transfer advantages commonly observed across interdisciplinary contexts.

At the practical level, educators can advance the application of 4C/ID around a “minimum viable approach” without significantly overhauling existing curricula. First, replace fragmented lists of knowledge points with “task clusters,” establishing at least a basic sequence of “representative tasks—variation tasks—transfer tasks” within a single course (Biggs & Tang, 2022), while defining deliverables and assessment criteria for each task. Correspondingly, provide conceptual frameworks or strategic paradigms as supporting information before tasks, offer procedural guidance through step cards or checklists during task execution, and embed micro-exercises for high-frequency, error-prone sub-skills within the overall task flow (Frerejean et al., 2019; Carless & Boud, 2018). Second, predefine “scaffolding withdrawal thresholds” and “reflection periods,” explicitly specifying withdrawal conditions and timing within lesson plans and classroom flows. Formative assessment should permeate the entire process, delivering actionable, immediate feedback through quizzes, checklists, self/peer evaluations, process documentation, and learning analysis reports to support gradual scaffolding reduction and individualised support (Hattie & Timperley, 2007; Means et al., 2013). Third, technology should serve complex tasks rather than dominate them: employ virtual simulations or remote fieldwork for high-authenticity, high-risk scenarios to facilitate initial familiarisation and mid-process reinforcement; introduce computer-supported formative assessment and learning analytics in contexts requiring process tracking and individualised support(Argelagós et al., 2022; Xu et al., 2024); utilise gamified or interactive micro-tasks during intensive procedural practice phases to boost practice frequency and engagement (Akkaya & Akpinar, 2022). For large classes and resource-constrained settings, implement station-based/rotational organisation and peer teaching assistantships (Freeman et al., 2014). Break down complex tasks into assignable work packages, clearly defining feedback responsibilities for instructors, teaching assistants, and peers at different stages (Carless & Boud, 2018). Concurrently deploy implementation checklists or fidelity checklists to ensure all four elements are present, scaffolding is withdrawn as planned, and feedback is timely (Hattie & Timperley, 2007). Prepare high-fidelity substitute scenarios for critical stages when authentic environments are unavailable (Divon & Ghosal, 2024).

From the perspective of courses and projects, task clusters and assessment criteria should span the entire semester, progressively increasing complexity and autonomy. At the program or project cluster level, higher-order transfer can be achieved through cross-course task chains, transitioning from foundational operations to integrated projects, and ultimately to industry-simulated scenarios (Postma & White, 2016). To ensure sustainable improvement, it is recommended to incorporate implementation fidelity and learner process data into routine quality assurance. Utilise longitudinal trajectory evidence to continuously calibrate task granularity, scaffolding withdrawal timing, and the intensity of technological interventions. In summary, the theoretical framework and practical pathways outlined above are corroborated by the evidence presented in this review. They provide an operational blueprint for educators to rapidly, cost-effectively, and replicably adopt 4C/ID, while also establishing a traceable process foundation for subsequent design optimisation and effectiveness evaluation.

Evidence Quality and Study Limitations

Based on the MMAT quality assessment results (Figure 2), the studies included in this review generally performed well in terms of measurement tool appropriateness and outcome data completeness, with relatively clear reporting of intervention processes and evaluation procedures. However, control of confounding factors and implementation of randomisation were commonly inadequate, and efficacy analyses and long-term follow-up were relatively lacking. Consequently, the support for causal inference and external validity was somewhat limited. Although mixed-method studies demonstrated reasonable methodological integration and consistency with research questions, individual studies still exhibited insufficient reporting on the validity and reliability of quantitative/qualitative components, sampling, or procedures. Overall, the existing evidence is robust in terms of “direction consistency,” but caution is warranted in interpreting its “inference strength” and “generalisability.”

Beyond methodological quality, this review also exhibits several systemic biases and scope limitations. First is publication bias: inclusion primarily focused on peer-reviewed journal articles, failing to systematically cover grey literature (e.g., technical reports, unpublished manuscripts, dissertations), potentially overestimating positive effects. Second is language bias: searches were restricted to Chinese and English, potentially omitting relevant studies from other linguistic regions (e.g., Western Europe, select Latin American countries), affecting geographical representativeness. Third, research design limitations: most studies were non-randomised quantitative designs (including single-group pre-post tests), with insufficient random allocation, stratified/paired designs, and covariate control. Longitudinal/delayed post-tests were rare, making it difficult to assess learning retention and distant transfer. Measurement primarily relied on questionnaires and written tests; while performance tasks and process evidence (e.g., logs, operational traces, learning analytics data) appeared in some studies, standardised protocols remain absent. Finally, implementation contexts (class size, teacher resources, platform and resource availability) and task fidelity (degree of four-element implementation, scaffolding withdrawal pace) varied across studies. This reflects the adaptability of 4C/ID while potentially introducing additional heterogeneity.

The conclusions drawn from this review are best interpreted as directional evidence and actionable guidance: In multidisciplinary higher education settings, the 4Cs/ID framework aligns with the “overarching task-scaffolding reduction-immediate feedback” mechanism, demonstrating overall positive learning and transfer outcomes. However, given the absence of strict randomisation, confounding control, and long-term follow-up, the causal strength and external validity require further validation through more rigorous research. Future research should enhance design rigor and reporting standards (e.g., effect sizes, power analyses, fidelity measures, and multi-source evidence) while maintaining contextual authenticity to strengthen the robustness and generalisability of findings.

Future Research Directions

Future research should further enhance the rigor of study design and the strength of evidence. While maintaining contextual authenticity, prioritise the use of contextualised randomised or stratified, matched quasi-experimental designs. Clearly define control conditions and conduct efficacy analyses, standardising the reporting of effect sizes and confidence intervals. For mixed-methods studies, clearly articulate the integration logic and connection points, strengthening the traceable fusion of quantitative and qualitative evidence.

Regarding measurement and time scales, performance-based task scoring and process data (such as logs, operational traces, and learning analytics) should be routinely employed and triangulated with questionnaires or written tests. Cognitive load assessments should integrate subjective scales with task-level indicators to distinguish intrinsic, extrinsic, and learning-related loads. Implement delayed post-tests and cross-course/cross-setting tracking to examine immediate, intermediate, and long-term transfer effects and their retention. Simultaneously monitor implementation fidelity and dose-response relationships to define minimum effective doses and cost-effectiveness thresholds.

Regarding the extension of contextual externalisation and mechanism coupling, it is necessary to expand into non-STEM, humanities and arts fields, as well as settings with diverse cultural and resource conditions. This involves examining the moderating effects of learner heterogeneity (e.g., baseline proficiency, self-efficacy). Focusing on virtual simulation, formative assessment, learning analytics, and gamified micro-tasks, we will evaluate their role in reducing extrinsic load while activating learning-related load. Additionally, we will explore the optimal timing and intensity of adaptive scaffolding and intelligent feedback within task sequences. It is recommended to adhere to open and reproducible standards, sharing materials, code, and anonymised data within ethical boundaries to facilitate multi-site collaboration and subsequent meta-analyses. This approach will accumulate evidence and enhance external validity.

Conclusion

This systematic review comprehensively examines the empirical application of the 4C/ID model in higher education contexts, analysing research characteristics, implementation pathways, and pedagogical outcomes. Findings indicate that included studies exhibit diverse geographical and disciplinary distributions, with non-randomised quantitative research predominating and supplemented by a limited number of mixed-method approaches. Implementation commonly employs a holistic task framework supplemented by supporting information, procedural guidance, and partial practice, with scaffolding reduction and immediate feedback applied as task complexity progresses. Regarding outcomes, multidisciplinary evidence consistently indicates that 4C/ID enhances the quality of performance-based tasks, knowledge integration, and transfer. It also positively impacts non-cognitive outcomes such as learning engagement, satisfaction, and self-efficacy. With appropriate task sequencing, feedback, and assessment support, cognitive load is effectively regulated.

At the same time, the strength of evidence inference should be viewed with caution: existing research still has limitations in controlling for confounding factors, randomisation, and long-term follow-up, resulting in limited external validity and scope for causal interpretation. Based on this, this paper proposes actionable recommendations for educators (e.g., task cluster design, scaffolding withdrawal thresholds, process evidence, and technology augmentation) and improvement directions for researchers (e.g., contextualised randomised or stratified/matched designs, effect size and efficacy reporting, triangulation of performance and process data, fidelity and dose-response monitoring, longitudinal and distant transfer measurements).

Overall, the 4C/ID framework demonstrates consistent directional advantages in higher education. Its structured pathway—comprising "overarching tasks, scaffolded reduction, and immediate feedback"—provides a replicable implementation framework for acquiring and transferring complex skills. Moving forward, enhancing research design rigor while maintaining contextual authenticity, alongside refining measurement and reporting standards, holds promise for further solidifying the evidence base. This would enable the development of more generalizable instructional design principles and practical guidelines.

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