D-CREDO Project

Digital Health Technologies-augmented Clinical Reasoning Education

Teaching Clinical Reasoning enhanced by digital tools: A White Paper

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Abstract

This white paper presents a conceptual and methodological framework to support educators to educate digital health tools into clinical reasoning (CR) education for undergraduate medical and nursing students. CR is a vital ability for healthcare professionals, enabling accurate diagnosis and safe decision-making. However, there is a growing disconnect between how CR is traditionally taught and how it must be practiced in modern, technology-enhanced clinical settings.

Developed as part of the D-CREDO project, this paper aims to clarify the consortium's approach to extending the existing DID-ACT curriculum on CR by incorporating digital technologies such as electronic health records (EHRs), clinical decision support systems (CDSS), Large Language Models (LLMs), mobile health (mHealth) apps and wearables, and telehealth technologies. The framework is underpinned by four key learning theories: Cognitive Load Theory, Experiential Learning Theory, Distributed Cognition, and Reflective Practice. These provide the educational foundation for integrating digital tools into both the teaching and assessment of CR.

The paper identifies several major challenges in digital CR education, including a lack of shared definitions, limited theoretical grounding, insufficient empirical evidence, and the mismatch between digital tool design and educational needs. To overcome these barriers, the framework proposes a set of structured learning objectives and instructional approaches such as blended learning and case-based learning with virtual patients. To address these gaps based on a rapid review of the literature, the white paper offers actionable recommendations for educators, higher education institution management, policy makers, and CR education researchers. The goal is to develop a comprehensive framework for equipping future healthcare professionals to reason effectively and ethically using digital tools, ultimately improving patient outcomes in a rapidly evolving healthcare landscape.

Introduction and background

Clinical reasoning (CR) is the cognitive process that healthcare professionals (HPs) use to assess patient information, formulate diagnostic hypotheses, and make evidence-based decisions. It is widely recognized as an essential competency across the health professions and as a cornerstone of effective clinical practice and patient safety (Higgs et al., 2018). In both medicine and nursing, strong CR abilities underpin the ability to provide safe, high-quality care, as failures in reasoning can lead to misdiagnosis or treatment errors (Durning et al., 2024). Given its importance, CR education is a central focus in health professions training.

Modern healthcare is undergoing digital transformation. A wide array of digital technologies – from electronic health records (EHRs) and clinical decision support systems (CDSS) to artificial intelligence (AI) applications, mobile health (mHealth) tools, and telehealth platforms – are now integrated into patient care (Zainal et al., 2022). These innovations are reshaping how information is collected, analyzed, and applied in CR, and can even provide timely, evidence-informed suggestions or support that complement the HP's own judgment. Today's digital health ecosystem is profoundly influencing the context in which CR occurs, requiring HPs to skillfully navigate electronic information systems, interpret algorithm outputs, and integrate digital data streams into their reasoning process.

Despite the digital evolution of healthcare, there remains a significant disconnection between current CR education and the realities of technology-enhanced practice. Undergraduate medical and nursing programs have been slow to incorporate training on these digital tools. Graduates often feel underprepared to effectively use EHRs, CDSS, and other digital tools when they enter clinical practice (Kleib et al., 2021). Studies have identified gaps between the digital skills taught in health professions curricula and those needed in modern workplaces (Zainal et al., 2022). For example, students may learn the principles of diagnostic reasoning through cases or bedside teaching, but receive minimal exposure to using an actual EHR or a CDSS as part of that reasoning process (Montanga et al., 2025).

This educational-practice gap means that new health professionals must often learn to reason with digital tools on the fly. The current misalignment might not only diminishes graduates' confidence in using technology, but also signifies a lost chance to enhance CR education with the same tools that graduates will eventually rely on in practice.

The D-CREDO project aims to fill this gap by developing a collection of new learning units for health professions students and their teachers on the use of digital health tools in education. The goal is not to create another CR education resource, but to extend the already established international, longitudinal curriculum on CR called DID-ACT (https://did-act.eu) with new elements. The DID-ACT curriculum is based on three basic pedagogical principles: learner-centeredness, blended learning, and case-based learning (Hege et al., 2023). While we intend to continue developing the collection of learning units in this spirit, the introduction of digital tools into CR education brings new challenges that require updating and extending the former educational model.

Key Challenges in Integrating Digital Tools into CR Education

Integrating digital technologies into CR education is a complex task, and several key challenges have been identified in bridging the gap:

- **Lack of conceptual clarity:** There is not yet a shared conceptual framework for "digital" CR. CR itself has been defined differently across medicine and nursing, often in different ways (Young et al., 2020). Our previous work aimed to clarify differences in how the term CR is defined across professions (Huesmann et al 2023), yet several questions remain that can continue to cause confusion. Adding technology can further complicate the concept.
- **Limited theoretical grounding:** The theories guiding digital integration into CR are underdeveloped. For example, He et al. (2017) noted that despite numerous best-practice

reports, there is rarely a unifying educational theory underpinning how trainees learn to use EHRs in a way that improves reasoning. Many educational initiatives involving health technologies have arisen ad-hoc, without a strong theoretical basis. We have few proven models explaining how students learn CR with digital support, or how digital contexts might alter cognitive processes (Lee et al., 2025).

- **Evidence gaps:** Empirical evidence on best practices for integrating digital tools into CR education remains limited. To date, most literature on using tools like EHRs in training consists of descriptive reports or small pilots, with few longitudinal or controlled studies (Omar, 2019). Without robust evidence, curriculum developers and policymakers lack needed guidance on which approaches best enhance learning versus those that are merely novel. This lack of evidence makes it challenging to build a compelling case for investment and curriculum change at large scale.
- **Design misalignment:** A practical challenge is the misalignment between clinical software design and educational needs. Many digital systems in healthcare are designed for efficiency in practice, not for teaching novices (Pusic et al., 2023). Furthermore, most technologies are not tailored to learners – they may assume clinician-level prior knowledge or may bypass the reasoning processes that educators want students to practice. On the curriculum side, existing teaching methods might not take advantage of these tools. Careful alignment of tool design, user training, and curricular context is needed to make digital integration effective.

Objective and intended readership

In light of these challenges, the objective of this white paper is to propose a comprehensive conceptual and methodological framework for integrating digital tools into CR education.

Our aim is to provide health professions educators with an evidence-based approach to bridging the gap between traditional CR training and the digitally enhanced environment of contemporary healthcare.

This framework will outline principles for incorporating technologies such as EHRs, CDSS, AI in image analysis, Large Language Models (LLM) and big data, (mHealth)apps and wearables, and telehealth into both the teaching and assessment of CR. By doing so, we seek to ensure that the next generation of physicians and nurses are not only adept at CR, but are also prepared to effectively leverage digital resources as an integral part of their reasoning process.

The scope of our analysis is focused on undergraduate medical and nursing education. We concentrate on the formative training years in which students develop core CR competencies, typically through methods like reflective practice, case-based learning and blended learning. Key teaching and assessment methods relevant to CR can include the use of virtual patients, concept mapping, automatic feedback, and non-workplace-based assessments and these methods are considered in terms of how they can incorporate digital health tools elements. We also ground our framework in established learning theories applicable to CR (e.g. cognitive load theory, experiential learning theory, reflective practice, and situativity theories) to ensure that integration of technology aligns with how students learn best. While our focus is on undergraduate education, many principles likely extend to graduate and continuing education; however, discussion of postgraduate training falls outside our current scope. By clearly defining the scope, we aim to provide actionable insights tailored to the undergraduate level, where establishing sound CR habits is most critical.

Relevance

The issues addressed in this white paper have a wide significance. Around the world, educational leaders and policymakers in health professions education are grappling with how to prepare students for a technology-rich clinical environment (Zainal et al., 2022). By offering a cohesive framework for integrating digital tools into CR education, we intend to support international dialog and collaboration on this important reform. The recommendations herein are crafted to be adaptable across different countries and institutional contexts, acknowledging that there is no one-size-fits-all solution but that shared principles can guide local innovation. In sum, this white paper's forward-looking framework aspires to inform global efforts in modernizing CR education, ultimately improving patient care outcomes through better-prepared HPs.

Conceptual framework

Defining CR

There is no single universally accepted definition of CR – different authors and professions emphasize various facets of this complex construct (Ten Cate & Durning, 2017). CR can be defined as *"a skill, process, or outcome wherein clinicians observe, collect, and interpret data to diagnose and treat patients"* (Daniel et al., 2019). This encompasses both conscious and unconscious cognitive operations, influenced by context and the patient's unique circumstances (Daniel et al., 2019). Similarly, Durning et al. (2024) characterize CR as *"the cognitive and affective steps up to and including arriving at a diagnosis and management plan that is specific to a patient's circumstances and preferences."* Despite minor differences in wording, these definitions highlight that CR is a complex process that involves many facets and thinking processes.

Beyond its definition, CR is widely recognized as a core competency in health professions education. It is considered a defining characteristic of effective practice in both medicine and nursing, because sound reasoning underpins accurate diagnoses and safe patient management (Gold et al., 2022). In fact, major competency frameworks (e.g. CanMEDS) explicitly list CR or clinical decision-making as a fundamental skill for practitioners (Daniel et al, 2019). In undergraduate programs, CR is often taught as an integral part of the curriculum, emphasizing that students must learn *how to think* like a clinician, not just what to think. Daniels et al. (2019) note that effective CR is central to clinical competence and ultimately to patient safety. Therefore, clarifying what CR entails and ensuring learners understand its importance is a critical first step in any educational framework.

In summary, we define CR in this paper as *"CR encompasses health professionals' thinking and acting in assessment, diagnostic and management processes in clinical situations taking into account the patient's specific circumstances and preferences"* (Huesman et al., 2023). This definition will guide our subsequent discussion of how to teach and augment CR skills in the digital era.

Teaching CR

Teaching CR presents a complex challenge, primarily because it involves making invisible cognitive processes visible and accessible to learners. Much of this reasoning occurs subconsciously or automatically in experienced HPs, making it difficult to articulate in a way that novices can easily understand and internalize. Bridging this gap between expert intuition and novice learning requires deliberate effort and thoughtful educational design (Delany & Golding, 2014).

CR is commonly acquired through apprenticeship-based educational models. These include time-honored methods such as bedside teaching, ward rounds, case-based discussions, and observation of senior clinicians in practice. Within these settings, learners observe, absorb, and imitate the thought processes of experts, often without explicit instruction on how decisions are made (Kulkarni et al., 2025). The emphasis lies in immersion: reasoning is demonstrated, but not always explained. Although this is a well-established method, increasing attention is being paid to the pre-clerkship phase, where students are given more opportunities to actively practice and develop both knowledge and reasoning skills.

In the pre-clinical phase of nursing and medical education more explicit and structured teaching of CR is taught. This evolution reflects the growing recognition that learners benefit from direct engagement with the cognitive strategies involved in clinical problem-solving (Kulkarni et al., 2025). Classrooms and simulation settings now offer safe, reflective environments where these strategies can be practiced deliberately. By clearly articulating the steps and mental operations used by clinicians, educators can break down reasoning into teachable components, helping students to learn how to think like a clinician.

Ultimately, foundational CR is developed through structured teaching must be reinforced and deepened through hands-on practice during clerkships and real-world clinical encounters. As students assume more responsibility in clinical environments, their reasoning becomes more nuanced, adaptive, and aligned with the complex realities of patient care. In this way, CR education is not a one-time intervention, but an ongoing developmental process that evolves in tandem with clinical expertise—supporting safer, more effective, and more reflective medical practice.

Role of Digital Health Technologies in CR Education

The rise of digital health technologies in clinical practice is profoundly influencing how CR is performed – and by extension, how it should be taught. Modern HPs regularly interact with EHRs, CDSS, medical reference apps, and even (or in future) AI tools as part of their clinical reasoning (Durning et al., 2024). However, until recently there has been a gap in education: many health professions trainees receive little formal training in the use of these digital tools for reasoning. For example, medical students often graduate with limited experience in navigating an EHR or incorporating a decision support alert into their clinical thinking (Milano et al., 2014). A key element of the D-CREDO project is to address this gap and create learning units where students practice CR in scenarios or cases that include realistic tasks, so that they learn to use digital tools effectively and appropriately in the environment they will eventually work in.

Learning Theories to consider

There are several learning theories that provide a conceptual basis for why and how certain strategies may work in CR education. We highlight four key theoretical perspectives relevant to CR training: cognitive load theory, experiential learning theory, situativity theories (particularly distributed cognition), and reflective practice. Each offers insights into how learners acquire reasoning skills and how instructors can optimize the learning process.

Cognitive load theory (CLT). CLT describes how humans process information, highlighting the constraints of working memory. Learning occurs effectively when new information transitions from limited-capacity working memory into long-term memory, where it is stored as enduring schemas (Sweller & Chandler, 1991; Sweller, 2019). Thus, instructional design should carefully manage the cognitive "load" placed on learners' working memory.

In CR education, cognitive demands are substantial, particularly for novice learners such as nursing and medical students still developing foundational medical knowledge (Si, 2024). These learners frequently encounter cognitive overload when engaging with complex clinical scenarios because many elements of the task are new and require explicit, conscious processing. CLT categorizes cognitive load into three types—intrinsic, extraneous, and germane—whose interplay determines the total cognitive burden experienced during learning activities (Mancinetti et al., 2019).

Applying CLT principles, educators can structure CR teaching to effectively manage the cognitive workload. For instance, instructors might simplify case presentations, segment complex clinical problems into smaller, manageable tasks, or provide explicit cognitive scaffolds such as schemas or checklists. Such structured approaches help reduce extraneous load by eliminating irrelevant or confusing information and controlling intrinsic load by breaking down complex cases. This instructional strategy allows learners to allocate more mental resources towards germane load, which directly contributes to schema formation and deep learning (Si, 2024).

CLT-based strategies in CR training can help enhance students' knowledge retention and increased engagement when learning activities align with cognitive capacities. By gradually increasing complexity and providing structured guidance, educators ensure learners progressively build robust mental models of CR processes (Leppink & Van Den Heuvel, 2015).

The integration of CLT with digital health tools in CR education is particularly relevant in the context of D-CREDO. Digital tools, when designed according to CLT principles, can further reduce unnecessary cognitive load and offer learners structured guidance that aligns closely with cognitive architectures. Hence, educators and instructional designers in digital health-augmented CR education are encouraged to systematically incorporate CLT principles, optimizing learning outcomes and supporting sustained student engagement.

Experiential Learning Theory (ELT). ELT offers a useful framework for CR education by emphasizing learning through active engagement, reflection, and application. Unlike traditional didactic methods that often create a gap between theoretical knowledge and real-world application, ELT is grounded in the idea that learners build and refine understanding through cycles of experience, making it highly suitable for clinical education (Sugarman, 2014; Pal et al., 2022).

The core assumption of ELT is that learning is facilitated through the provision of experiences. The learning process can be divided into four interrelated phases. First, concrete experience involves participation in a novel situation or a familiar experience viewed from a new perspective. Second, reflective observation encourages learners to think critically about the experience and identify discrepancies between what occurred and their prior knowledge. Third, abstract conceptualization supports the development of new concepts or the refinement of existing mental models that integrate theory and practice. Finally, active experimentation involves applying the newly acquired knowledge to different contexts, thereby testing and refining it through action (Bathje et al., 2022; Pal et al., 2022).

This cyclical process closely mirrors how CR develops: students initially encounter clinical cases, reflect on these experiences, extract meaningful principles, and then apply this learning to new cases. Through repeated engagement with this cycle, learners gradually internalize more sophisticated reasoning strategies. Research shows that ELT improves medical students’ cognitive and affective capabilities by involving them in authentic experiences supported by reflective and iterative practice (Ahmad et al., 2024).

To implement ELT in CR education, educators can integrate approaches such as bedside teaching, case discussions, and problem-based learning (Spencer, 2003; Choi et al.,2023). These strategies enable learners to apply theoretical knowledge in real-world contexts while also fostering reflection and discussion. Structured debriefings, reflective journals, and guided self-assessment activities help solidify the learning gained from each experience. ELT supports the idea that true learning emerges not simply from experience itself, but from thoughtful reflection on that experience.

The integration of ELT with digital health tools in CR education is particularly relevant in the context of D-CREDO. Health technologies should be embedded in learning activities that themselves follow the experiential learning cycle. Educators must create experiences that enable students to not only practice CR but also understand how to thoughtfully use health technologies in clinical contexts. The goal is not simply to teach how health technologies work, but how they can be a valuable asset to support the CR process in real-world settings. In this way, ELT provides a pedagogical foundation for transforming CR education enhanced by health technologies into meaningful educational experiences. When thoughtfully applied, experiential learning helps students develop the deep, flexible CR skills necessary for effective practice in modern, technology-enhanced healthcare environments.

Situativity Theories – *Distributed Cognition (DCog)*. DCog, as part of the broader family of situativity theories, offers an effective framework for understanding and teaching CR in healthcare. In the white paper, we focus on describing DCog theory from among the group of situativity theories, which also include Embodied Cognition, Ecological Psychology, and Situated Cognition (Parsons et al., 2025), as it is the most relevant to the use of digital health tools. Rather than viewing cognition as an activity confined to the individual mind, DCog frames it as distributed across people, artefacts, tools, locations, and time. This theory emphasizes that reasoning unfolds in real-world contexts where individuals interact with physical tools, digital systems, and other individuals to achieve cognitive goals.

At the core of DCog are two foundational principles (Hollan et al., 2000). First, it expands the unit of analysis from the individual to the entire cognitive system, which may include clinicians, digital devices, documentation artefacts, and clinical environments. Second, it broadens the concept of cognitive mechanisms to encompass not only mental representations but also interactions with external elements, such as checklists, displays, EHRs, and verbal communication. These distributed processes can be social (among team members), material (via tools and environments), and temporal (drawing on actions and decisions across time).

In CR education, this means that CR is not solely an internal, mental process, but a system-level activity shaped by collaboration, technology, and context (Boyle et al., 2023a). For example, interprofessional teams often co-construct diagnoses through shared discussions, while clinical decisions are scaffolded by digital artefacts such as CDSS or even AI-generated outputs. DCog highlights the importance of training students not only in individual reasoning skills but also in how to operate within and contribute to distributed systems of reasoning.

The DCog theory has important implications for the use of digital health tools in the context of the D-CREDO project. Digital tools should not be considered separate add-ons to reasoning but rather integral parts of the reasoning system. They shape how information is perceived, remembered, and acted upon. Tools such as EHRs, large language models, and telehealth platforms can extend clinical cognition by distributing perceptual and interpretative tasks, connecting multiple professionals, and embedding reasoning across time and place.

Educators are therefore encouraged to create learning environments that reflect the distributed nature of real clinical work. This involves using authentic tools and settings in teaching, such as simulated EHRs, AI-assisted case simulations, or team-based problem-solving activities. In these settings, students can practice thinking with tools and within systems, not just as isolated individuals.

By embedding DCog into the education design, CR education becomes more authentic and context-sensitive (Boyle et al., 2023b). It prepares students to navigate the complex, tool-mediated, and team-based nature of modern healthcare reasoning, equipping them with the skills to think critically and collaboratively in distributed environments.

Reflective practice. Reflective practice is a foundational approach to professional learning that emphasizes the iterative process of critically evaluating one's actions, decisions, and experiences. It includes both reflection-in-action (while performing a task) and reflection-on-action (after the task), fostering metacognitive awareness and continuous learning. Thus reflective practice is not simply about looking back, but about constructing meaning, identifying areas for improvement, and connecting theory with practice in a thoughtful and purposeful manner (Sladyk & Sheckley, 2009).

In the context of CR education, reflective practice is particularly significant. It enables learners to analyze how they interpret clinical data, formulate differential diagnoses, and respond to changing clinical scenarios. Through structured reflection, students can identify knowledge gaps, cognitive biases, and reasoning errors, thereby enhancing diagnostic accuracy and decision-making (Almonamni et al., 2021). Practices such as deliberate reflection, where learners pause to consider alternative diagnoses and overlooked information, have shown to significantly improve learning and performance, particularly in complex cases (Mamede & Schmidt, 2022).

Educators foster reflective practice in CR through strategies like guided debriefings, reflective journals, think-aloud demonstrations, and feedback sessions. These methods encourage learners to become more self-aware and responsible for their own reasoning processes. Importantly, reflective practice is not a one-time activity but a habit of mind that continues throughout professional life, supporting lifelong learning and ethical clinical behavior (Kuiper et al., 2017).

The integration of reflective practice with digital health tools is highly relevant in the context of D-CREDO. The goal is not only to teach students how to use digital technologies, but to embed their use within reflective learning practices that enhance students' understanding of when, why, and how to apply them in clinical contexts. This means designing educational experiences where digital technologies contribute to concrete reasoning scenarios that learners then reflect upon.

Rather than allowing technology to bypass critical thought through automation, educators must embed mechanisms for reflection in digital learning environments. This could include reflective prompts, feedback mechanisms, or opportunities for peer discussion and self-assessment. In doing so, students not only gain technical proficiency but also develop the reflective capabilities necessary to use technology responsibly and insightfully in patient care.

By embedding reflective practice across the learning journey, educators must ensure that digital health-augmented clinical education remains grounded in thoughtful, adaptive reasoning. This approach supports the development of HPs who are not only technologically competent but also critically reflective and committed to continuous improvement in complex care environments.

Together, these learning theories, cognitive load management, learning from experience, distributed cognition, and reflection, form the conceptual foundation for our approach in incorporating digital tools into CR teaching. They ensure that our methods are aligned with the manner in which students best learn: through the delivery of well-structured challenges, active involvement in real or simulated environments, interacting with others, considering context and resources, and reflective thinking to guide experience into improved expertise. This theoretical grounding will inform the practical framework and recommendations of the next sections of this white paper. Each educational intervention or strategy that we recommend can be traced to one or more of these foundation theories, providing an explanation as to why it should enhance learning of CR within a digitally enriched healthcare environment.

Digital Tools in CR Education

Building upon the conceptual framework, the D-CREDO project aims to bridge the educational-practice gap by equipping health professions students and educators with skills to effectively utilize digital health tools in CR. This initiative fosters a generation of healthcare professionals adept at integrating these technologies into clinical education while enhancing educators' proficiency in embedding digital tools into existing curricula.

D-CREDO Classification of Digital Tools

Based on an extensive needs analysis (https://d-credo.eu/), we have identified five primary classes of digital health tools crucial for contemporary CR education:

- AI in image analysis

- Large Language Models (LLM) & big data
- mHealth apps & wearables
- Electronic Health Records (EHR) & Clinical Decision Support Systems (CDSS)
- Telehealth

Digital Tools and CR

AI in Image Analysis

AI technologies, particularly deep learning models such as convolutional neural networks (CNNs), enhance CR through improved accuracy, the extension of perceptual capabilities beyond human senses, and increased efficiency in interpreting medical images. Despite these advantages, significant challenges include dataset bias, automation bias, limited explainability of AI-driven recommendations, and transferability of models across diverse populations. Clinicians must, therefore, employ critical appraisal skills, contextualizing AI insights within CR. This aligns closely with the experiential and distributed cognition frameworks, where active engagement, a division of labour between human and artificial intelligence that expands the horizon of observation, and reflection on AI-assisted insights form critical learning experiences.

LLM & Big Data

LLMs applications, such as ChatGPT, and big data analytics offer transformative capabilities for summarizing medical information, supporting diagnostic hypotheses, and facilitating rare disease identification and management. However, ethical and practical challenges like data privacy, accuracy of generated information (hallucinations), and data misuse necessitate caution. Educators should apply principles from cognitive load theory and reflective practice, emphasizing structured guidance to navigate these challenges and encouraging students to critically evaluate AI-generated outputs.

mHealth Apps & Wearables

mHealth apps and wearable devices provide real-time patient data that enrich the CR process, especially in personalized and continuous care scenarios. They can act as external memory aid (e.g. storing vital signs, symptom logs) and can offload cognitive tasks (e.g. tracking trends or detecting anomalies). CR abilities are necessary to evaluate app credibility, patient compliance, and the integration of app-generated data into care plans. The integration of experiential learning cycles into curricula allows students to actively experiment, reflect, and conceptualize patient monitoring data effectively.

EHR & CDSS

EHR systems centralize patient data, facilitating comprehensive CR, while CDSS tools provide evidence-based recommendations and enhance diagnostic accuracy. Despite their utility, clinicians face cognitive overload and automation bias risks. Poor usability of EHR interfaces may contribute to losing track of connections within patient data or to the perpetuation of incorrect information. Leveraging cognitive load theory, educators must teach structured methods to mitigate information overload and critically evaluate CDSS outputs, emphasizing thoughtful integration within clinical workflows.

Telehealth

Telehealth significantly reshapes CR by shifting healthcare delivery from physical to virtual environments (e.g. video consultation rooms or virtual therapeutic and rehabilitation platforms). Clinicians must adapt diagnostic or management processes to limited physical examination capabilities and remote data synthesis. This adaptation aligns with situativity theories, highlighting the changed context of reasoning and distributed nature of cognition across digital communication technologies. Reflective practice methods further enable clinicians and students to thoughtfully navigate telehealth interactions, focusing on patient-centered communication and shared decision-making.

Learning Objectives for Digital Tool Integration

To effectively integrate digital health tools into CR education, D-CREDO has developed a structured set of learning objectives. These begin with overarching goals relevant across all tools and learning environments and are further specified for both students and educators. The objectives are also organized by the type of digital tool involved (e.g., EHRs, CDSS, LLMs, mHealth, telehealth). This layered structure supports students in acquiring essential competencies and helps educators design purposeful, tool-specific teaching strategies.

For example, by the end of a course module, students should be able to:

1. explain the potential benefits of digital technologies in clinical reasoning and list their strengths and limitations.
2. discuss the ethical and legal aspects of using digital technologies in the clinical reasoning process.
3. evaluate the validity and reliability of the output of digital technologies in the clinical reasoning process.

The full set of learning objectives, including detailed versions tailored to specific tools and target audiences, can be found in **Appendix 1**.

Methods for Teaching and Assessing Digital Tools in CR Education

In the previous chapters, we established the conceptual foundations (e.g. cognitive load management, experiential learning, distributed cognition as an example of situativity theory, and reflective practice) and proposed key digital health tools for CR. Building on that framework, we explore how to teach and assess the use of digital tools in CR education. We focus on evidence-based teaching methods that engage students in active, technology-enhanced learning, and on assessment approaches that support learning (formative) and measure competence across contexts. Throughout, we connect these methods to the foundational theories explaining how they promote the development of CR skills in a digital context.

Teaching Methods for Digital technologies in CR

Effective teaching of CR with digital tools requires learner-centered strategies that integrate technology into authentic clinical scenarios. Two cornerstone approaches are blended learning (BL) (often via a flipped classroom model) and case-based learning (CBL) with Virtual Patients (VPs). These methods emphasize active learning, alignment of asynchronous and synchronous activities, and guided reflection, all aligned with how learners can build reasoning abilities.

Blended Learning

Blended learning is a meaningful combination of (asynchronous) online and face-to-face (F2F) teaching and learning (Hege et al., 2020). A common BL design is the flipped classroom, where students first engage with foundational content online (e.g. interactive modules, videos, quizzes) before class, and then use class time for higher-order application and problem-solving (Hege et al, 2020). Other BL formats include doing online activities after a classroom session (to reinforce or extend learning), or integrating online elements *during* in-person sessions (for example, using a simulated EHR or digital quiz live in class) (Liu et al., 2016). Crucially, all phases, whether online or in-person, must be well-aligned and build upon each other in a coherent learning progression. This alignment ensures that students can transfer and apply knowledge gained asynchronously to the interactive activities that follow in class.

BL offers several advantages for CR education. First, the asynchronous phase allows structured self-directed learning at the student's own pace (Tolks et al., 2016). Novice learners can review digital tool tutorials or clinical content in a low-pressure setting, which helps manage cognitive load, they form initial schemas without the time pressure of class (reducing extraneous load). Second, the synchronous phase can then be devoted to active learning: discussing cases, practicing with digital tools, and solving clinical problems, rather than delivering basic lectures. This approach is more student-centered, as learners are actively applying concepts (supporting ELT by providing "concrete experiences”). A systematic review in health professions education found that BL *significantly outperforms traditional classroom teaching* for knowledge acquisition (Vallée et al., 2019). Findings suggest that a well-designed blend of online and in-person activities can enhance learning efficiency and effectiveness.

In the context of digital tools enhancing CR education, a blended learning unit might unfold as follows: in an online preparatory module, students read about a tool (e.g. clinical decision support systems) and perhaps watch a video demonstration. They may complete an e-quiz or a guided tutorial with an embedded simulation of the tool. This preparatory work primes them with essential knowledge (ensuring *intrinsic cognitive load* is manageable). Next, in a F2F-session, students work in small groups to discuss a clinical case that requires using the tool, for instance, practicing diagnostic reasoning on a case where they use a mock CDSS. The teacher facilitates discussion, addresses misconceptions from the prep work, and poses questions that leverage learners to higher-order thinking. This synchronous phase should be interactive. A follow-up online phase can then reinforce learning: for example, students might interact with a virtual patient case individually to apply the tool in a new scenario, receiving automated feedback (discussed later) on their decisions. Finally, a brief subsequent (online) class could allow reflection and debriefing, helping students consolidate what they learned about both the clinical content and the tool’s use (Hege et al., 2020).

The success of BL in CR education depends on careful alignment and instructor preparation. Instructors must design the asynchronous and synchronous components to complement each other, avoiding duplication or gaps (Rowe et al., 2012). For instance, if students learn about an AI diagnostic app beforehand, the in-class task should explicitly build on that. This sequencing aligns with Instructional Design principles and helps manage cognitive load. Moreover, educators need to adopt a facilitator role: in a student-centered BL format, the teacher shifts from being a lecturer to a guide or coach (Tolks et al., 2016).

From a theoretical standpoint, blended learning resonates with multiple learning theories. By mixing self-paced study and interactive practice, BL inherently supports Experiential Learning Cycle, the online phase can provide abstract conceptualization (learning theory, facts) and perhaps a virtual “experience,” whereas the classroom phase offers concrete experience and active experimentation (e.g. running through clinical scenarios), followed by reflective observation in debriefs. BL also aligns with situativity theory by allowing some learning to occur in context-rich environments: for example, an in-class simulation with an EHR introduces the real-world context and social interaction, which distributed cognition theory argues are key for developing practical reasoning skills. Finally, BL encourages reflective practice: educators can build in reflection prompts during online modules (e.g. short quizzes with feedback that ask students to think about how they arrived at an answer) and during class (group discussion of why different diagnoses were considered). By interweaving these elements, a blended approach creates a *scaffolded, continuous learning experience* that is well-suited for mastering the use of digital tools in CR.

Case-Based Learning and Virtual Patients

CBL has long been used for teaching CR, students work through patient cases, applying knowledge to decide on diagnoses and management. In the digital era, case-based learning is enhanced by VPs, which are interactive computer simulations of clinical scenarios (Kononowicz et a., 2019). A VP typically presents a realistic patient case where the learner can take a history, review results, make diagnostic or therapeutic decisions, and see outcomes, all through a digital interface. VPs allow students to practice CR in a safe, controlled environment that mimics real patient encounters (Kotwal et al., 2021). Key principles of VPs include authenticity (they feature realistic patient data, images, or videos), interactivity (learners actively make choices and see consequences), reproducibility (the same case can be revisited or used with many students), and feedback. By working through virtual cases, students can integrate clinical knowledge with decision-making skills without risk to real patients, which is ideal for deliberate practice of CR (and aligns with ELT's concrete experience stage).

Virtual patients make the "invisible" process of CR more visible and structured. As students' progress through a VP case, they must articulate or at least select their diagnostic hypotheses, rationale, and next steps, which externalizes their thinking. Many VPs are designed to prompt learners at critical junctures, for example, asking them to list differential diagnoses before revealing more information, or to justify why they order a certain test. This guides learners to engage in reflective thinking during the case, rather than just guessing passively. Studies have shown that using VPs can improve data gathering and diagnostic accuracy in learners. In fact, a recent systematic review (Plackett et al. 2022) found that a majority of studies (58%) reported positive effects of VP training on students' CR skills, especially in skills like data gathering, forming diagnostic ideas, and patient management.

One powerful aspect of VPs is the ability to provide immediate, tailored feedback on learners' decisions. Unlike a textbook case, a VP can respond to student inputs. For instance, if a student chooses an incorrect management step, the program can highlight that this choice led to a poor outcome or can prompt the student to reconsider. This immediate feedback allows learning through mistakes in a low-stakes setting (known as productive failure). A systematic review by Jay et al. (2024) specifically looked at VPs that provide feedback on CR and concluded that well-designed VPs use a variety of feedback methods to effectively coach students in reasoning. Learners reported that such feedback helped them reflect on their thought process and identify gaps in their clinical approach.

Importantly, VP platforms can be integrated with the same digital tools that students will use in practice, creating an authentic digital environment for learning. For example, a VP case might be linked to a simulation of the EHR interface, so that students practice navigating a patient's chart, reviewing lab results or past notes, and documenting the progression of their CR. This not only teaches CR but also the practical skill of using an EHR effectively. Similarly, a VP can include a built-in CDSS: as the student works up the case, an on-screen CDSS panel might offer evidence-based suggestions (or even "alerts" if the student's plan misses a critical issue), and the student learns to interpret and either accept or question the CDSS. By doing so in a simulated case, the student practices critical appraisal of decision support in a safe space, echoing the distributed cognition principle that reasoning is often shared with tools. VPs can also present AI-generated content, for instance, incorporating an AI-analyzed chest X-ray or ECG into the case for the student to interpret alongside their own reasoning. This trains the student to integrate AI outputs with clinical judgment, and if the VP provides an explanation of the AI result, it furthers the student's understanding of the tool's reasoning.

Through these integrations, VPs become a way of applying multiple digital tools in a coherent clinical context. This teaches not only tool-specific skills but the holistic ability to CR with digital support, as happens in modern practice. It reflects the tenets of distributed cognition theory by having students practice reasoning as a system, interacting with patient information, AI outputs, EHR interfaces, etc., rather than reasoning in isolation. It also encourages reflective practice: many VP systems prompt learners at the end of a case to reflect on their performance ("What would you do differently? Which cues did you miss?") or even have built-in debrief modules. Educators can enhance this by reviewing VP case reports with students, fostering reflection-on-action (e.g. discussing why a student arrived at a wrong diagnosis and how to avoid that error).

Assessment Methods for Digital CR

Assessing CR, especially in the context of digital tool use, is challenging due to the complex, cognitive, and context-dependent nature of CR. No single assessment can capture all facets of CR performance. Therefore, educators emphasize multiple methods and frequent feedback rather than sole reliance on high-stakes exams. In this section, we discuss assessment strategies that not only evaluate learners' proficiency in digital-augmented CR but also *promote learning during the assessment process*. We focus on formative assessment principles, the spectrum of assessment methods with emphasis on non-workplace-based tools as outlined by Daniel et al. (2019), and the role of automated feedback mechanisms that leverage technology to guide learners and improve their self-regulation and decision-making accuracy.

Formative Assessment

Formative assessment refers to assessment for learning, ongoing evaluations embedded in the learning process that provide feedback to students to guide improvement (Wood, 2018). In contrast to summative assessments, which are assessments *of* learning (e.g. a final exam to certify competence), formative assessments are low-stakes checkpoints used during a course or curriculum. Their primary purpose is to inform students of their progress, clarify expectations, and identify areas needing work, all in a timely manner so that students can adjust their approach. Key principles of formative assessment include: providing specific, actionable feedback rather than just scores; being timely (ideally immediately or soon after performance); and fostering self-reflection and self-regulation in learners (Norcini et al., 2019). For example, a formative assessment in a learning unit or course could be a quiz after a digital tools workshop that not only tells the student which answers were correct, but explains the reasoning or concept behind each question.

In CR education, formative assessment is particularly valuable because CR is a complex ability that benefits from iteration and feedback. Students often cannot see their own reasoning errors without guidance. Formative activities like think-aloud exercises, reflective journals, or virtual case analyses with feedback can make the reasoning process explicit. This aligns with reflective practice theory: by getting feedback, learners are prompted to reflect on their decision-making and thereby become more aware of their cognitive processes (Yardley et al., 2012). It also ties to germane cognitive load in CLT. When a student engages with feedback and reflects, they are investing germane load to reorganize their knowledge structures (schemas) for better future performance (Young et al., 2014). Additionally, formative assessment often involves social and contextual interactions (discussions with faculty, feedback within simulated scenarios), echoing distributed cognition theory: learning emerges through participation and feedback in realistic contexts (Durning & Artino, 2011).

One powerful model that embeds formative assessment is programmatic assessment (PA). In a programmatic approach, assessment is not a one-off event but a coordinated program of multiple assessment points, each designed to collect information on the learner's performance in different domains of competence (Van der Vleuten & Schuwirth, 2005). Each data point (e.g. a clinical evaluation exercise, a VP case score, a reflective essay) is relatively low-stakes by itself, but collectively they build a rich picture of the learner's abilities. The emphasis is on combining multiple sources of data to inform coaching and high-stakes decisions (if needed) (Schuwirth & Van der Vleuten, 2011). PA also stresses continuous feedback, every piece of assessment is returned with feedback, and students have opportunities to act on that feedback before the next assessment. Over time, patterns in the data can be used by faculty coaches to mentor the student.

The concept of programmatic assessment is supported by assessment experts like van der Vleuten and Schuwirth (2005), who note that focusing on a holistic collection of assessment evidence leads to fairer and more meaningful evaluation in complex domains like CR. Instead of trying to make each single test perfectly reliable and valid for all of CR, programmatic assessment accepts that each method has limitations, but by using complementary methods, the weaknesses of one are compensated by the strengths of another. The 2019 scoping review by Daniel et al. echoed this: after reviewing dozens of CR assessment tools, the authors concluded that ensuring competence in CR *"requires the* *development of programs of assessment that address all components of CR,"* constructed of multiple methods to account for each method's biases and gaps. Ensuring all key components of CR are sampled (data gathering, hypothesis generation, problem representation, diagnosis, management, etc.) is a core goal.

Non-Workplace-Based Assessment Methods

Non-workplace-based assessments (non-WBAs) are methods of assessing CR that do not involve direct observation in clinical or simulated patient encounters. Instead, they typically use standardized formats like written or computer-based tests. According to Daniel et al. (2019), non-WBAs encompass tools such as multiple-choice questions (MCQs), extended matching questions, key feature exams, script concordance tests (SCTs), concept mapping exercises, modified essay questions, and other written case problems (Daniel et al., 2019). These formats usually present clinical scenarios and ask learners to make decisions or answer questions about diagnosis or management. Non-WBAs are common in medical education because they are efficient to administer to large groups, can be objectively scored, and often have good reliability for assessing knowledge application.

In the context of CR, non-WBAs target certain components of the reasoning process better than others. Their strength tends to lie in assessing knowledge application, diagnostic conclusions, and management decisions. For example, a key feature examination presents a short case vignette and asks about the *critical decision* at a key juncture, thereby testing whether the learner can identify the crucial action for an uncommon or tricky aspect of the case.

However, non-WBAs generally are less effective in assessing the earlier, dynamic phases of CR, such as how learners gather information or generate hypotheses (Anderson et al., 2021). A multiple-choice exam, for instance, doesn't observe *how* a student would take a history or what thought process they use to arrive at the answer – it only evaluates the end result (did they pick the correct diagnosis?). Daniel et al. noted that many commonly used non-WBAs (MCQs, extended matching, etc.) are *"ineffective during the evaluation of information gathering, hypothesis generation, and problem representation,"* whereas they do well in assessing diagnostic decisions and management plans (Anderson et al., 2021). On the other hand, assessments that involve actual performance (like OSCEs or real patient encounters) are better suited to evaluating those initial reasoning steps. This is why a mix of methods is recommended: for a complete picture of CR ability, one might use non-WBAs to test knowledge-based reasoning across many conditions (breadth), and simulated to observe reasoning in action (depth).

Non-WBAs do offer significant practical advantages. They allow broad sampling of content (Henry & West, 2019). This broad sampling improves content validity and can ensure students reason through both common and rare scenarios. Non-WBAs also have typically standardized scoring (one best answer, etc.), yielding high reliability and easier psychometric analysis. Daniel et al. (2019)

categorize concept maps and comprehensive integrative puzzles (CIPs) also as non-WBAs. These are more innovative formats that try to assess a learner's CR structure. For example, a concept map assessment might ask a student to draw a schematic linking clinical findings to possible diagnoses to treatments, revealing how the student organizes knowledge and priorities in a case (Kononowicz et al., 2023). Concept mapping has an added benefit that it can be a learning activity *and* an assessment: by constructing a map, students actively integrate knowledge, and instructors can assess the connections they make. In fact, the use of concept maps as a formative tool has been noted to help students form *"cognitive networks"* of clinical knowledge. Such networks are the basis of illness scripts that underpin expert reasoning. Therefore, integrating concept map exercises into CR training can serve dual purposes – teaching students to visually organize their reasoning and providing instructors a window into the student's thought process.

Non-WBAs might be used formatively more than summatively within the curriculum. The constructive alignment principle suggests that we should assess what we teach; since we are teaching students how to use tools like CDSS or telehealth in reasoning, we should also assess those skills. Non-WBAs can be adapted to this: a key feature exam including a scenario about using a CDSS appropriately, or an SCT that includes input from an AI tool as part of the vignette, asking students to weigh that information. This ensures our assessments encourage students to learn not just the "medical knowledge" but the application of that knowledge in a tool-rich environment.

Automated Feedback

One of the exciting opportunities in digital education is the use of automated feedback **mechanisms** to enhance learning and assessment. Automated feedback refers to feedback that is generated by a system (software, algorithm, AI) and delivered to the learner instantly based on their performance (Çiçek et al., 2024; Jay et al., 2024). In CR training, this often takes the form of a digital platform that tells a student whether their decision was correct or not and provides an explanation or hint, without needing a human instructor to intervene at that moment. Examples include: a virtual patient program that immediately critiques a diagnosis choice, an intelligent tutoring system that poses a question and then gives a model answer for comparison, or an AI chatbot that evaluates a student's clinical summary for omissions.

The primary benefit of automated feedback is immediacy. Research in learning has shown that immediate feedback, when well-crafted, can strongly reinforce learning by allowing learners to correct mistakes in real-time (Choi et al., 2020). Immediate feedback closes the gap between action and consequence, the student doesn't continue practicing something incorrectly for long before being steered in the right direction. This is particularly crucial in CR, where misconceptions can otherwise persist. By acting as an *"educational mirror,"* automated feedback lets the student instantly verify their reasoning steps and outcomes (Choi et al., 2020).

High-quality feedback is key: it should be specific, understandable, and related to the cognitive process, not just a generic “wrong” message (Schuwirth & Van der Vleuten, 2006). For example, rather than just saying “Incorrect”, an automated tutor might say “Incorrect, you overlooked the patient’s family history, which is a critical risk factor here.” This kind of feedback prompts reflection and helps the student learn the underlying principle. It also supports metacognition by encouraging students to think about their thinking: they must consider “What did I miss? Why did that choice seem right to me initially?”. Over time, repeated cycles of action and feedback help students internalize expert reasoning patterns. Indeed, studies show that immediate feedback, especially combined with requiring the learner to reflect or correct their answer, can improve diagnostic accuracy and CR (Jay et al., 2024).

Automated feedback is commonly implemented in virtual patient systems and simulation software (Cook et al., 2025). As mentioned earlier, a VP can be designed to give feedback at each decision node. For example, after a student selects a diagnosis in a VP, the program might show a pop-up: “Correct, the most likely diagnosis is X because of Y and Z findings”. Some systems might allow the student to proceed regardless, but they’ll carry that feedback forward (perhaps affecting the outcome), while others require the student to reconsider before moving on. Both approaches enforce a reflective pause.

In the context of digital tools, automated feedback can be tailored to tool-specific competencies. For example, a module on mHealth data interpretation might show a student a patient’s wearable data trend; if the student’s conclusion ignores a clear abnormal pattern, the software could hint “Notice the trend at 02:00, what might that indicate?” thereby pointing them to revisit the data. In terms of theoretical alignment, automated feedback clearly draws on Cognitive Load Theory: it can reduce extraneous load by clarifying confusion immediately and prevent learners from spending excessive mental effort on unproductive paths. Experiential learning benefits as well, the concrete experience of making a decision is immediately followed by reflective observation (through feedback), before the learner moves to abstract conceptualization (understanding the general principle from the feedback) and then can actively experiment again in the next case.

By integrating these approaches, learning units and courses can provide a rich, supportive learning environment. Students will *learn by doing*, engaging deeply with digital tools in realistic case-based contexts, and *learn by reflecting*, through continuous feedback and assessment that guide improvement. This dual emphasis on innovative teaching and thoughtful assessment will produce undergraduates who are not only adept at using digital health technologies, but who can also reason critically and adaptively in the complex clinical settings of modern healthcare. Each teaching and assessment method we choose can be traced back to our foundational theories, ensuring that our educational practices are evidence-based and tuned to how learners acquire expertise. In the next sections, we will examine gaps in the literature and identify areas for further research, but the principles outlined here will serve as a blueprint for designing and implementing the D-CREDO curriculum in practice.

Literature Analysis and Evidence Gaps

To inform the D-CREDO curriculum development, a rapid literature review was conducted covering literature from January 2019 until September 2024. The search strategy targeted three facets: CR domain, digital tool type, and educational context. The full report can be found on https://d-credo.eu/wp-content/uploads/2024/12/D2.1-D-CREDO-Rapid-literature-review.pdf.

Gaps in research and practice

While the rapid review highlights a growing body of literature on digital tool integration in CR education, it also exposed critical gaps in current research and practice. Notably, the distribution of studies was uneven across tool types, geographic regions, and educational focus, suggesting imbalances that curriculum developers and future researchers should actively address.

Below we discuss these gaps in depth:

- **Underrepresented Tool Categories:** Certain digital tools, particularly telehealth, mHealth apps & wearables, and AI for image analysis, are scarcely represented in the CR education literature. This underrepresentation does not imply these tools are unimportant; rather, it highlights that educational strategies for them might be underdeveloped. Educators currently have little evidence for teaching students how to reason with, for example, continuous patient-generated data or AI diagnostic imaging support. The imbalance may stem from the surge of interest in others (the dominance of LLMs applications like ChatGPT overshadowing research into telehealth training, for instance). This gap calls for proactive development of teaching models and scholarly evaluation in the more neglected areas, so that curricula can encompass the full spectrum of digital competencies needed in modern practice.
- **Lack of Theoretical Grounding:** The review found that relatively few studies anchored their educational interventions in formal learning theories or frameworks. Only 4 of the 46 papers explicitly used an educational or cognitive theory to inform the design of the learning. This lack of robust theoretical underpinning means many initiatives are ad hoc or purely descriptive. Without theory, it is harder to generalize findings or build upon them systematically. For example, a digital case simulation might improve test scores, but if it's unclear *why*, replication and optimization are challenging. The minimal attention to theory also risks missing opportunities to leverage known effective pedagogies when introducing complex digital tools. Going forward, researchers should aim to frame studies in terms of learning theories to provide explanatory power and guide design choices. For practitioners,

aligning digital tool usage with established educational principles will likely yield better outcomes.

- **Geographic and Contextual Imbalance:** The evidence is heavily skewed toward high-income Western settings. Over half of the included studies were from North America (primarily the US), with substantial representation from Europe and East Asia, but virtually none from low- and middle-income countries. This imbalance is problematic because the availability, adoption, and relevance of digital health tools can differ greatly by region and resource setting. For instance, telehealth might be common in one country but rare in another due to infrastructure; likewise, decision support systems might be integrated in some health systems but absent elsewhere. The scarcity of studies from diverse contexts means we do not know if the current educational approaches are generalizable or how to adapt them culturally and logistically. It also means that the Global South is underrepresented in shaping this aspect of health professions education. It might indicate a missed opportunity to promote greater equity through digital health technologies, in response to shortages in the health professions workforce and teaching capacity in low- and middle-income countries.
- **Uneven Focus Across Professions:** The review's inclusion criteria centered on medical and nursing students, and indeed 29 studies involved medical students and 11 involved nursing. Only 1 study explicitly included an interprofessional mix of med/nursing. This highlights that within even our narrowed scope, medicine has received the lion's share of attention, with nursing education somewhat less so. The relative lack of nursing-specific investigations suggests a gap where certain disciplines might have unique needs or challenges when learning to use digital tools. For future practice, ensuring all health graduates are competent in digital-enhanced reasoning will require extending research and development beyond medicine alone. Curriculum designers should consider collaborative, interprofessional learning activities that bring different student groups together around digital tool use, and researchers should evaluate such approaches.
- **Limited Attention to Assessment and Feedback:** Another notable gap is the relative lack of focus on how learners' CR performance with digital tools is assessed and how feedback is provided. Only 13 studies (about 28%) explicitly examined assessment strategies related to digital CR abilities, and even fewer described detailed feedback mechanisms. While many papers measured outcomes, there was minimal discussion of formative assessment or feedback loops during the learning process. One exception was the few studies with built-in AI feedback, but these were the minority. The general silence on feedback suggests that educators implementing these tools might not be systematically capturing or responding to student reasoning errors and misconceptions. This is a critical gap because feedback is known to be a key driver of learning. The implication is that current implementations may not be maximizing

learning gains, because students could be using new tools without receiving adequate guidance on their performance. For curriculum design, this highlights the need to integrate clear assessment criteria and feedback opportunities whenever a digital tool is used for CR training. Research should also explore assessment methods and guide the development of feedback models for digital learning environments.

- **Minimal Focus on Faculty Development:** Lastly, the review revealed that very few studies (only 9 of 46) addressed faculty roles or development in the context of using digital health tools in CR education. Most papers described student-facing interventions and outcomes, but paid little attention to how faculty are prepared to teach with these technologies or how their attitudes influence adoption. If educators themselves are not comfortable with AI or EHR systems, they may underutilize these tools or fail to integrate them meaningfully into teaching. The absence of literature on faculty training programs, support frameworks, or even expert consensus on best teaching practices for digital CR suggests a significant practice gap. The implication is that without investment in faculty skills and confidence, even well-designed student interventions may falter. Going forward, institutions should consider parallel "train-the-trainer" initiatives whenever new digital tools are introduced into the curriculum, and researchers should document and evaluate these faculty development efforts.

In summary, these gaps, in content coverage, theoretical grounding, global reach, professional breadth, assessment rigor, and faculty support, highlight that the field of digital CR education is still in an early stage. Addressing these deficiencies will be crucial for the next generation of curriculum design and scholarly work. The findings underscore a need for more balanced and theory-informed research that not only explores new tools but does so across diverse contexts and with an eye toward comprehensive educational strategies.

Open Research Questions

To guide future efforts in integrating digital tools into CR education, we propose the following open research questions for educators and researchers:

Effects of Digital Tools on CR Processes

1. How does the use of digital tools (e.g., CDSS, LLMs) influence the CR process of healthcare students when working with VPs? Under which circumstances or contextual factors do these changes occur?
2. What are the effects of automated versus instructor-guided feedback on students' CR performance?

3. How do students interpret different forms of AI-generated explanations (e.g., heatmaps vs. textual explanations in chest X-rays) when solving VP cases?
4. What cognitive strategies do students use when navigating EHR data to formulate differential diagnoses or management plans?
5. How can performance in EHR-based reasoning tasks be reliably and validly assessed in undergraduate education?

Learning Design and Cognitive Load

6. How does the use of digital health tools affect cognitive load in CR novices versus experts?
7. What is the optimal moment, considering both learning effects and cognitive load, to introduce digital tools for CR in healthcare education?

Interpersonal and Group Dynamics in Digital CR Education

8. What types of prompts effectively stimulate collaborative group processes during VP case discussions?
9. What is the impact on students' patient-centered attitudes when engaging in shared decision-making with a peer-student role-playing the patient compared to a ChatGPT-simulated patient?

Interprofessional and Ethical Considerations

10. How do medical and nursing students perceive their own and each other's roles in managing mHealth technologies during CR?
11. What ethical tensions do students encounter when managing cases remotely via telehealth in different clinical settings?

Faculty Development

12. What faculty development strategies are needed to effectively prepare educators to integrate digital tools into CR instruction?

Recommendations and Best Practices

Building on the evidence and gaps identified, this chapter provides actionable recommendations for integrating digital tools into CR education. The recommendations are organized by learning theories, teaching methods, and assessment methods, ensuring that each reflects best practices from literature.

Learning Theories recommendations

Educational interventions should be explicitly grounded in learning theory to address the current lack of theoretical underpinning in many digital CR learning scenarios. By aligning with proven theories, educators can design digital learning experiences that optimize cognitive development and skill acquisition. Key recommendations include:

Cognitive Load Theory (CLT):

1. *Align case complexity with learners' experience level*
   Start with simple cases for novices and gradually introduce more complex scenarios as students gain competence.
2. *Chunk complex cases into manageable steps*
   Design digital learning activities with clear segmentation, guiding learners through distinct reasoning stages (e.g., data gathering, interpretation, diagnosis).
3. *Reduce extraneous cognitive load*
   Eliminate irrelevant content or distracting interface features in digital tools and simulations.
4. *Provide structured reasoning aids*
   Incorporate scaffolds such as checklists, flowcharts, or diagnostic frameworks to support CR.
5. *Offer pre-instruction before tool use*
   Include tutorials, walkthroughs, or demonstrations before expecting students to independently use digital tools in CR.

Experiential Learning Theory:

1. *Embed digital tools in realistic, experience-based learning activities*
   Use VPs, simulated EHRs, or telehealth scenarios that closely resemble actual clinical situations.
2. *Ensure active decision-making by students*
   Design digital cases that require learners to collect data, make diagnostic or management decisions, and observe outcomes.
3. *Follow every digital experience with structured reflection*
   Plan guided debriefings, peer discussions, or instructor-led reviews immediately after the case activity.
4. *Link each experience to abstract concepts*
   Use post-case discussions to help students generalize principles (e.g., diagnostic heuristics, patient safety risks) from the case experience.
5. *Enable repeated practice and feedback across varied cases*
   Offer multiple VP scenarios with different complexities and contexts, allowing students to apply and refine CR skills through iterative learning.

Distributed Cognition Theory:

1. *Design simulations that replicate real clinical environments*
   Use virtual patients or case scenarios that integrate realistic interfaces such as simulated EHRs, CDSS, or telehealth platforms.
2. *Train students to reason with and through digital tools*
   Include tasks where learners retrieve, interpret, and apply information using the same types of tools they will encounter in clinical practice.
3. *Incorporate collaborative CR tasks*
   Structure exercises that require students to reason together, ideally in interprofessional groups (e.g., medical and nursing students).
4. *Highlight the social and contextual nature of reasoning*
   Use joint reasoning tasks and think-aloud sessions to make reasoning processes explicit and visible to peers.

Reflective Practice:

1. *Embed structured reflection into all CR activities*
   Design each learning activity with a deliberate moment for reflection, before, during, or after engagement with digital tools.
2. *Integrate reflective writing tools*
   Assign short reflection tasks, such as journals or structured response forms, where students document reasoning errors, uncertainties, or insights gained.
3. *Use guided debriefing protocols*
   Implement standardized debrief formats (e.g., “What went well? What was challenging? What would you do differently?”) after digital simulations.
4. *Make reflection a routine habit throughout the curriculum*
   Reinforce regular reflective opportunities across modules to cultivate metacognitive skills and long-term self-monitoring habits in CR.

Teaching Methods – Blending Digital Tools into Pedagogy

To effectively teach CR enhanced by digital tools, educators should adopt active, learner-centered methods that integrate technology into case-based learning. Recommended best practices include:

Blended Learning:

1. *Adopt a flipped-classroom model*
   Assign foundational digital modules (e.g., videos, tutorials, quizzes) before in-person sessions to prepare students with core knowledge.

2. *Use class time for active, higher-order learning*
   Focus face-to-face sessions on applying knowledge to real-world cases, using digital tools like EHRs or CDSS in group-based CR tasks.
3. *Ensure tight alignment between online and in-class activities*
   Design the online content to directly support and lead into classroom exercises; avoid disconnected or repetitive content.
4. *Design online content that includes interaction and feedback*
   Include formative quizzes or interactive simulations in online modules to engage learners and assess understanding prior to class.
5. *Provide clear instructions and expectations*
   Communicate the purpose and connection of each phase (online/in-person) to students, so they understand the blended learning flow.
6. *Use blended learning to integrate digital tool proficiency and CR*
   Ensure that digital health tool use is embedded in both the online and in-person phases, for example, using a mock CDSS online and practicing its interpretation in class.

Case-Based Learning with Virtual Patients:

1. *Incorporate VP simulations regularly into the curriculum*
   Schedule VP cases as recurring learning activities (e.g., weekly assignments or preparatory tasks in blended learning modules).
2. *Use VPs to enable safe, realistic reasoning practice*
   Provide students with interactive cases where they can make decisions and experience consequences without risk to real patients.
3. *Vary case complexity and content*
   Offer a range of VP cases covering different clinical conditions and difficulty levels to build flexible reasoning skills and illness scripts.
4. *Design cases to support deliberate practice*
   Structure VP activities to focus on key CR skills such as data gathering, hypothesis generation, diagnostic decision-making, and management planning.
5. *Link VP activities to broader learning goals and theory*
   Make explicit how VP exercises align with course objectives and CR competencies; discuss how they relate to real clinical decision-making and tool use.

Assessment Methods, Supporting and Measuring CR Skills in a Digital Era

Robust assessment strategies are essential to encourage learning and to verify competence in CR with digital tools. We recommend a shift toward assessment for learning using a programmatic approach that combines multiple methods and emphasizes feedback:

Formative Assessments (with Automated Feedback):

1. *Embed formative assessments throughout the curriculum*
   Integrate regular, low-stakes assessments into digital CR learning activities to track progress and promote continuous learning.
2. *Use digital tools to deliver immediate, automated feedback*
   Leverage e-learning platforms and virtual patient systems to provide instant, personalized responses after each learning task or decision.
3. *Focus feedback on reasoning, not just correctness*
   Ensure that feedback explains why an answer is correct or incorrect, especially in relation to CR steps (e.g., cue interpretation, hypothesis generation).
4. *Use quizzes and digital cases as learning tools, not just assessments*
   Design quizzes and VP exercises that double as educational experiences by embedding rationale and feedback directly into the activity.
5. *Time feedback to support learning and adjustment*
   Provide feedback promptly, ideally immediately, so learners can apply it to subsequent tasks or cases while the experience is still fresh.

Programmatic Assessment:

1. *Use a mix of complementary assessment methods*
   Combine multiple assessment formats (e.g., quizzes, virtual patient performance, OSCEs, reflective essays) to capture the full range of CR skills.
2. *Balance breadth and depth*
   Include non-workplace-based assessments for wide content sampling (e.g., key-feature exams), and simulation or workplace-based tools for observing reasoning in action.
3. *Collect multiple low-stakes data points over time*
   Use learning management systems, VP platforms, and digital tool logs to gather longitudinal performance data for each student.
4. *Align assessment with learning*
   Design assessments as opportunities for learning by integrating feedback into each instance, supporting students' development and self-monitoring.
5. *Use longitudinal data for high-stakes decisions*

Base judgments about competence or readiness on aggregated performance across tasks, rather than one-off high-stakes exams.

Conclusions

In conclusion, this white paper has highlighted the critical role of digital tools in transforming CR education and outlined how thoughtful integration of these tools can address current educational gaps. We began by examining the conceptual foundations, drawing on CLT, ELT, DCog, and reflective practice to understand how students learn CR in the context of digital tools and how digital interventions can be optimized. We then surveyed the landscape of digital tools and their current uses in health professions training. While these technologies offer opportunities, we also identified challenges and gaps: many curricula don't explicitly teach CR skills, some important tool domains remain underrepresented, and assessments of reasoning often falls behind, with sparse feedback.

Key findings from the rapid review and analyses include the importance of making CR with digital tools an explicit focus of teaching, the demonstrated efficacy of methods like blended learning and VPs in improving reasoning outcomes, and the necessity of aligning any digital learning activity with pedagogical principles. By applying learning theories, educators can reduce cognitive overload and scaffold learning for novices, provide rich experiential cycles that promote deeper understanding, situate learning in real-world contexts, and cultivate a habit of reflection that will serve learners throughout their careers. Additionally, we underscored that assessment and feedback must be integral to the learning process, because students benefit enormously from timely feedback on their reasoning and from a variety of assessment approaches that collectively capture the multifaceted nature of CR.

Taken together, these insights point to a future in which digital tools are not a novelty or add-on, but a part of CR education. When used thoughtfully, technology can augment traditional teaching, provide meaningful practice opportunities, and ultimately improve diagnostic accuracy and patient care by educating clinicians who are both technically prepared and strong thinkers. We have also acknowledged that this integration of digital health tools in CR curricula is still in its early stages globally, with much work to be done to generalize best practices across health professions.

Call to Action

To modernize CR education, we call on educators, institutions, and policymakers to act. Educators should integrate digital tools into their teaching, making CR processes explicit and applying best practices such as blended learning, reflection, and feedback. Institutions must invest in infrastructure and faculty training, embed digital competencies throughout curricula, and promote interprofessional learning. Policymakers should prioritize digital CR education in accreditation, fund resource development and training, and support innovation and collaboration. Together, we can equip future healthcare professionals to reason effectively and confidently in a technology-driven healthcare environment.

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Appendix 1: Learning Objectives

General

At the end of the course students are able to ...

4. explain the potential benefits of digital technologies in clinical reasoning and list their strengths and limitations.
5. discuss the ethical and legal aspects of using digital technologies in the clinical reasoning process.
6. evaluate the validity and reliability of the output of digital technologies in the clinical reasoning process.
7. evaluate the use of digital technologies in various clinical settings considering factors such as timing, workload, workflow, and integration in the healthcare team.
8. make and justify clinical decisions based on data from digital technologies.
9. explain the meaning and value of the output of digital technologies in an understandable manner appropriate to the target group.

Educators are able to ...

10. teach the potential benefits of digital technologies in clinical reasoning and list their strengths and limitations.
11. teach the ethical and legal aspects of using digital technologies in the clinical reasoning process.

AI in Image Analysis

At the end of the course students are able to ...

12. use the output of the AI-generated image analysis to reflect on their own diagnostic process, such as making the differential diagnoses.
13. evaluate the impact of AI-generated imaging on clinical decision-making compared to conventional diagnostic methods.

Educators are able to ...

14. teach and adapt learning activities that challenge students to critically analyze and compare AI-generated results with those from conventional methods.

LLMs and big data

At the end of the course students are able to ...

15. evaluate potential influences on their own clinical reasoning process when using LLMs.
16. apply basic principles of prompt engineering to effectively use LLMs for their clinical reasoning process.

Educators are able to ...

17. teach basic principles of LLMs, supporting students to effectively and responsibly use LLMs in their clinical reasoning process.

mHealth apps and wearables

At the end of the course students are able to ...

18. integrate mHealth technologies into shared decision-making, taking into account patient preferences and context.
19. describe how mHealth apps and wearables can be used in routine patient care, for instance continuous patient monitoring and timely intervention.

Educators are able to ...

20. teach and adapt learning activities that enable students to integrate mHealth technologies to support their clinical reasoning process.

EHR and CDSS

At the end of the course students are able to ...

21. analyze and document patient data within the EHR and create management plans.
22. create management plans collaboratively with the healthcare team within the EHR.
23. use the CDSS effectively and responsibly in the clinical reasoning process.
24. monitor patient outcomes over time and adjust their strategies accordingly within the EHR.

Educators are able to ...

25. teach students' to effectively and responsibly use EHRs within the clinical reasoning process.
26. teach students' to effectively and responsibly use CDSS within the clinical reasoning process.

Telehealth

At the end of the course students are able to ...

27. explain when to use telehealth methods for consultation and remote diagnosis considering different contexts.
28. reflect on how the clinical reasoning process differs in a telehealth setting compared to in-person clinical setting, identifying the unique challenges and opportunities posed by virtual consultations.
29. conduct a simulated telehealth visit considering the boundaries of remote consultation.

Educators are able to ...

30. teach and adapt learning activities that prepare students to effectively apply clinical reasoning in a simulated telehealth setting.