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Enhancing Early Clinical Reasoning through Generative AI-supported Self-explanation: A Design-based Research Study in Preclinical Medical Education

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Abstract: Early clinical reasoning development is challenging because students struggle to transfer and reorganize biomedical mechanisms into causal models of clinical signs and symptoms. Drawing on illness script theory and generative learning theory, this design-based research developed and refined design principles for an innovative generative AI–supported self-explanation intervention. These principles promote early knowledge encapsulation and clarify how generative learning processes can support script formation in early clinical reasoning development.

Introduction

Clinical reasoning (CR) is a fundamental yet difficult competence to develop during the early years of medical education (Schmidt & Rikers, 2007). First-year students often learn biomedical mechanisms in isolation and find it hard to explain how these mechanisms account for clinical signs and symptoms. Their reasoning therefore remains descriptive rather than explanatory, delaying the encapsulation of biomedical knowledge into early illness scripts (Custers, 2015). Introducing clinical reasoning early can ease the transition from basic to clinical understanding, yet educators still struggle to help students connect mechanisms with manifestations and to support the construction of causal explanations rather than memorized descriptions. This study investigates how generative artificial intelligence (GAI) can scaffold self-explanation activities that promote early encapsulation of knowledge. The goal is to identify design principles that guide the use of GAI to support the development of early clinical reasoning.

Methods

A Design-Based Research (DBR) methodology was adopted, combining iterative cycles of design, implementation, and reflection. Two complementary theories informed the design. Illness script theory (IST) describes how biomedical knowledge becomes clinically meaningful through encapsulation and script formation (Custers, 2015; Schmidt & Boshuizen, 1993). Generative learning theory (GLT) emphasizes that learning deepens when learners actively select, organize, and integrate information through constructive processes such as self-explanation (Chi & Wylie, 2014). Together these theories framed the design of prompts and feedback intended to activate prior knowledge, stimulate causal reasoning, and encourage reflection.

The study was conducted in a first-year biomedical course at a Dutch medical school. Students interacted with a generative AI chatbot designed to guide self-explanation around clinical cases, structured into phases of knowledge activation (selection), narrative construction (organization and integration), and reasoning transfer (application). A total of 181 first-year medical students participated across five design cycles (R1: n=181; R2: n=69; R3: n=79; R4: n=64; R5: n=32). Data sources included conversation logs, questionnaires on motivation and cognitive load, and semi-structured interviews with students and tutors. Conversation logs were analyzed to examine students' engagement patterns, including interaction length, number of exchanges, and progression across phases. Interview data were analyzed thematically to complement the process data. The analysis was iterative across design cycles to examine how different scaffolding designs shaped students' engagement in generative reasoning processes and supported early script formation.

Results

Across the design cycles, the chatbot intervention evolved into a more coherent learning experience that supported early clinical reasoning development of students. Analysis of conversation logs indicated that embedding mechanistic prompts within authentic patient vignettes was associated with more integrated explanations, reflected in students more frequently linking underlying mechanisms to clinical signs and symptoms. Logs also

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suggested that exposure to multiple related cases supported transfer, with students increasingly applying similar causal reasoning across contexts.

Structuring the interaction into phases of knowledge activation, narrative construction, and reasoning transfer appeared to support a progression in students' reasoning. Conversation log analysis showed that prompts explicitly requiring "why" and "how" explanations were associated with increased generative engagement, reflected in longer interactions and more elaborated responses rather than isolated factual statements. Adaptive follow-up questions that invited students to refine or extend their responses appeared to sustain elaboration without directly providing answers, while reflective prompts supported the consolidation of understanding across phases.

Interview data further indicated that students experienced a shift from recalling facts to explaining why symptoms occur, describing the activity as supporting "thinking like a doctor." Students also reported that engaging with conceptually challenging topics and authentic clinical cases helped them better connect mechanisms to clinical findings and apply their reasoning across cases. These patterns suggest early integration of biomedical and clinical knowledge, consistent with initial stages of script formation. These findings informed a set of theory-informed design principles for AI-supported self-explanation.

Discussion

This study illustrates how a generative AI–supported self-explanation environment can help address a central challenge in early medical education: connecting biomedical mechanisms to clinical reasoning. The findings suggest that the structured dialogue supports a progression from knowledge activation to integration and transfer, aligning with key processes described in generative learning theory and facilitating early script formation as described in illness script theory.

From a theoretical perspective, the results provide insight into how generative learning processes may contribute to early script development. By engaging learners in explaining "why" and "how" mechanisms relate to clinical findings, the intervention appears to support the organization and integration of biomedical knowledge into more coherent, clinically meaningful representations. This suggests that structured self-explanation, when appropriately scaffolded, may initiate aspects of knowledge encapsulation even in preclinical stages.

This study contributes by articulating theory-informed design principles that explain how AI-supported scaffolding can foster generative reasoning and early script formation. These findings highlight the potential of AI to support iterative, learner-driven development of clinical reasoning in early medical education.

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