

Scaffolded Metacognitive Prompting in Asynchronous Online Discourse: An Empirical Analysis of Self-Regulated Learning Outcomes Among Undergraduate STEM Cohorts

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Abstract. This study examines the differential effects of scaffolded metacognitive prompting (SMP) protocols embedded within asynchronous online discussion forums on self-regulated learning (SRL) outcomes among undergraduate STEM students ($N = 312$) across two academic semesters. Drawing on Zimmerman's cyclical SRL model and Vygotsky's zone of proximal development, a quasi-experimental mixed-methods design was employed to compare SMP-integrated cohorts against control groups using standard instructor-led facilitation. Quantitative analysis of pre- and post-intervention assessments revealed statistically significant gains in cognitive monitoring ($d = 0.74$) and task strategy deployment ($d = 0.61$) within SMP cohorts. Qualitative thematic coding of forum transcripts further identified emergent epistemic agency patterns absent in control groups. Findings carry substantive implications for instructional designers and higher education policy frameworks targeting scalable, evidence-based online pedagogy.

Keywords: scaffolded metacognitive prompting, self-regulated learning, asynchronous online discourse, STEM undergraduate education, quasi-experimental instructional design, epistemic agency, cognitive monitoring, online discussion forum pedagogy, zone of proximal development

Introduction

The proliferation of asynchronous online learning environments across tertiary institutions has fundamentally restructured the epistemic conditions under which undergraduate students engage with disciplinary knowledge. By 2025, an estimated 65% of higher education institutions in OECD member states had integrated hybrid or fully asynchronous course delivery models into their standard curriculum offerings, a trajectory accelerated by post-pandemic pedagogical restructuring and sustained by institutional cost-efficiency imperatives (OECD, 2024). Within this landscape, the quality of discourse mediation—particularly the extent to which instructional scaffolding fosters genuine self-regulation rather than surface-level compliance—has emerged as a defining variable in determining equitable learning outcomes across diverse undergraduate populations. Self-regulated learning (SRL), broadly defined as the metacognitive, motivational, and behavioral processes by which learners proactively govern their own acquisition and application of knowledge (Zimmerman, 2002; Panadero, 2017), has long been associated with academic persistence, conceptual transfer, and disciplinary identity formation in STEM fields. However, the translation of SRL-supportive pedagogies into asynchronous online formats remains theoretically underdeveloped and empirically sparse. Traditional SRL interventions—such as reflective journaling, think-aloud protocols, and instructor conferencing—presuppose synchronous or at minimum low-latency interaction modalities that are structurally incompatible with the temporally distributed nature of asynchronous forums. This mismatch produces a critical pedagogical gap: students operating in asynchronous environments frequently default to performative contribution behaviors, submitting posts that satisfy formal participation rubrics without engaging the deeper cognitive monitoring processes that scaffold genuine knowledge construction (Garrison & Akyol, 2015; Xiao & Lucking, 2008). Scaffolded metacognitive prompting (SMP)—a structured intervention strategy in which targeted, sequentially tiered prompts are embedded within discussion thread architectures to elicit explicit self-monitoring, goal recalibration, and inter-peer epistemic evaluation—represents a theoretically coherent response to this gap. Grounded in Vygotsky's (1978) conceptualization of the zone of proximal development and operationalized through Flavell's (1979) taxonomy of metacognitive knowledge, SMP protocols have demonstrated preliminary efficacy in small-scale controlled classroom settings (Davis & Linn, 2000; King, 2002). Yet rigorous quasi-experimental evidence situating SMP within naturalistic asynchronous STEM undergraduate cohorts of sufficient statistical power remains conspicuously absent from the peer-reviewed literature, constituting the primary empirical lacuna this study addresses. This paper proceeds as follows: Section 2 presents a systematic review of SRL frameworks and existing metacognitive scaffolding interventions relevant to online higher education. Section 3 details the quasi-experimental mixed-methods research design, participant sampling procedures, instrumentation, and analytical protocols. Section 4 reports quantitative outcomes derived from pre/post-assessment comparisons and qualitative thematic findings from forum transcript coding. Section 5 discusses theoretical and practical implications for instructional design, curriculum policy, and faculty professional

development. Section 6 concludes with recommendations for scaled implementation and a delineation of study limitations and future research directions.

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