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A Knowledge-Capturing Environment to Support Writing of Engineering Papers

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Abstract

Scientific writing presents a persistent challenge for engineering educators and researchers because research progress is iterative, nonlinear, and exploratory. Contemporary theories of writing characterize scholarly composing as a recursive, knowledge-transforming process, motivating the need for environments that support flexible capture, organization, and revision. Building on early knowledge-capturing integrated design environments in engineering education [1], this paper presents a knowledge-capturing environment for STEM research writing using a Card–Deck–Board architecture. Cards capture discrete ideas (e.g., a claim, result, reference, or observation), Decks group related Cards into section-like collections, and Boards display multiple Decks simultaneously to support parallel development of a manuscript. The environment is implemented as a cloud-based workspace on a contemporary online writing platform and is designed to support persistent knowledge capture and real-time collaboration among multiple authors. The resulting framework is designed to support research paper development, proposal writing, and graduate thesis work across STEM disciplines

Introduction

Effective research writing is a critical competency for engineering educators and researchers, yet it remains one of the most persistent challenges for early-career faculty, graduate students, and professional engineers transitioning into academic research roles. Difficulties frequently arise not from a lack of technical expertise, but from the challenge of organizing evolving ideas, integrating growing bodies of literature. Across disciplines, graduate students report that literature-review and thesis writing are cognitively demanding and often overwhelming, in part because they must manage large amounts of information while synthesizing and revising [7], [8]. A central contributor to this difficulty is the nonlinear nature of the research progress: research rarely proceeds in a clean, sequential manner from hypothesis to method to conclusion. Instead, progress is marked by detours, false starts, reinterpretations of results, and continual reframing of research questions as new information is discovered. Literature reviews expand over time, experimental results prompt reconsideration of assumptions, and insights gained late in the process often retroactively reshape earlier sections of a manuscript. Thus many pieces of information have to be documented without knowing in advance which will ultimately prove essential, which makes an integrated environment desirable, providing an integrated framework to store and structure these disparate data pieces during research and paper writing. Knowledge-capturing integrated design environments (KCIDEs) provides a promising framework for addressing these challenges. In particular, Fu introduced a KCIDE framework for an undergraduate electrical circuits course that integrated multiple software tools and enforced a structured, multi-step problem-solving process [2] . Their system explicitly captured not only final solutions, but also intermediate reasoning, alternative approaches, and justifications for

methodological choices. This work demonstrated the pedagogical value of embedding knowledge capture directly into the workflow of engineering problem solving.
However, a key limitation of the original KCIDE framework lies in its assumption of a predominantly linear progression. The six-step process used in the circuits KCIDE was well matched to textbook-style problem solving, where problem definitions are fixed and solution paths converge toward known outcomes. In contrast, research writing operates in a far more open-ended and exploratory space. Additionally, the original KCIDE implementation functioned primarily as a desktop environment, limiting its capacity for continuous, evolving knowledge capture over extended research timelines. Modern research practice increasingly demands platforms that support ongoing, online, and easily updatable knowledge structures, enabling researchers to revisit, reinterpret, and collaborate on paper-writing as projects mature. These observations motivate the need for a nonlinear collaborative knowledge-capturing environment tailored specifically to STEM research writing, which can be accessed online. Such an environment must allow researchers to capture ideas at varying levels of maturity, preserve contextual relationships among concepts, and support large-scale reorganization without loss of meaning.

To address these challenges and the documented needs of STEM researchers, this work presents a digital knowledge-capturing environment using the platform of NovelPad, an online collaborative writing software designed to support modular, nonlinear organization of ideas [3]. The resulting system enables STEM researchers to document ideas, observations, literature insights, and conceptual developments in a flexible, non-sequential manner, as they come up, while simultaneously supporting real-time collaborative writing among multiple users. Rather than forcing early commitment to a fixed narrative structure, the platform allows knowledge to be captured opportunistically, reorganized dynamically, and refined collaboratively as research understanding evolves. Before introducing the design and implementation of this platform, however, it is important to review how contemporary theories of writing and communication fundamentally challenge linear models of composition and motivate the need for nonlinear, parallelizable knowledge-capturing environments.

Background

2.1 Contemporary theories of writing

Research writing in STEM is often treated as a linear activity that follows the completion of experimental or analytical work. However, extensive research in writing studies [2,4] and cognitive science have shown that this characterization is oversimplified. The foundational cognitive process model proposed by Flower and Hayes describes writing as a dynamic system composed of interacting subprocesses, which writers cycle through recursively rather than sequentially [2]. Writers continually revisit earlier ideas, revise goals, and restructure text as their understanding of the problem space evolves. Subsequent extensions of this model emphasize the role of working memory, problem representation, and goal management in shaping writing

behavior over extended periods [4]. These factors are especially salient in research writing, where cognitive load accumulates as literature grows, methods change, and interpretations evolve.

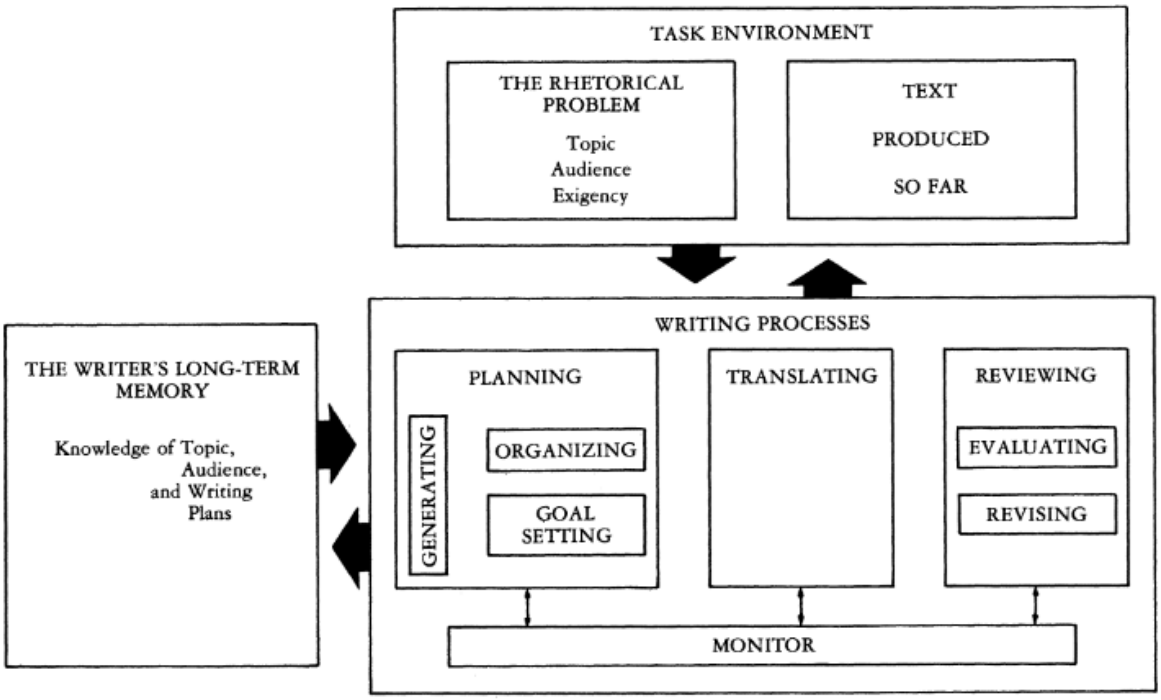


Figure 1: Fowler and Hayes' Model of Writing [2]

Complementing this view, Bereiter and Scardamalia distinguish between *knowledge-telling* and *knowledge-transforming* modes of writing [5]. In knowledge-transforming writing, writers actively restructure content in response to rhetorical goals and emerging constraints. Together these theories strongly suggest that effective research-writing environments must support: a) nonlinear revision and restructuring, b) persistent external representations of partial ideas, c) the ability to defer commitment to final narrative structure.

2.2 Knowledge Capture in Engineering Design Environments

Engineering education research has similarly emphasized that learning and assessment require access to process knowledge, not just final results. Integrated design environments have been developed to embed documentation, analysis, and reflection directly within engineering workflows. A notable example is the Knowledge-Capturing Integrated Design Environment (KCIDE) developed by Fu for an undergraduate electrical circuits course [1]. KCIDE integrates commonly used engineering tools at the time of publication and explicitly captures intermediate reasoning, alternative solution strategies, and the rationale behind methodological choices. KCIDE enforces a structured six-step problem-solving framework: define, present, alternate solutions, attempt, evaluate, rework/export. These are designed to scaffold student reasoning and

make problem-solving processes visible. From a pedagogical standpoint, this approach aligns well with constructivist learning principles and facilitates assessment by producing exportable documentation of student thinking. Yet, when examined through the lens of contemporary writing theory, its limitations for research writing become evident. First, KCIDE enforces a procedurally linear workflow. While iteration is possible, the framework presumes forward progression through predefined stages toward a known solution. This assumption is appropriate for textbook circuit problems but conflicts with the recursive, exploratory nature of research writing; writers frequently revise earlier sections after later discoveries, often redefining the research problem itself in response to new results or literature [2], [5].

Second, KCIDE was implemented as a desktop-based, single-user environment, reflecting the technological context of its development. Contemporary research writing is increasingly collaborative and distributed. Modern academic writing platforms emphasize real-time co-authoring, shared version history, and continuous updating to support the negotiation of meaning among multiple contributors [6]. These affordances directly support the recursive planning and revision processes identified in writing theory.

Notably, Fu and colleagues explicitly identified future extensions of KCIDE toward a client–server architecture to enable richer process capture and analysis [1]. This observation underscores that the conceptual foundation of KCIDE of capturing reasoning as it unfolds remains valid, while its architectural and procedural assumptions limit its applicability to open-ended research writing.

2.3 Toward Nonlinear, Collaborative Knowledge Capture

Taken together, contemporary writing theory and prior work on knowledge-capturing design environments motivate a shift away from strictly linear, stage-based workflows toward nonlinear, collaborative knowledge capture. In such systems, ideas can be captured opportunistically, as they arise in time, are reorganized flexibly, and refined over time as their relevance becomes clear. Contemporary writing tools increasingly adopt modular content units and spatial organization to support these needs. Modular interfaces allow writers to externalize partial ideas, maintain parallel lines of thought, and reorganize emerging structures without extensive rewriting. These design patterns align closely with cognitive models of writing and with the demands of long-term, collaborative research projects. This motivated us to incorporate modular, highly movable structures for knowledge capture. By integrating nonlinear organization with online, collaborative affordances, the proposed environment seeks to better align engineering research-writing tools with both established writing theory and contemporary research practice.

Implementation

This paper presents a knowledge-capturing integrated design environment for STEM research writing that explicitly supports nonlinear collaborative knowledge capture. The proposed framework adopts a movable, modular structure inspired by contemporary nonlinear writing theory. Knowledge is captured using three core organizational constructs: 1. Cards, which serve

as the fundamental unit of knowledge capture (each card represents a discrete idea, result, reference, or observation and can contain detailed text, equations, figures, or graphs; conceptually, a card corresponds to the granularity of a paragraph in a research manuscript). 2. Decks, which organize related cards into vertical collections analogous to sections of a paper, such as background, methodology, or results. 3. Boards, which present multiple decks simultaneously within a single workspace, allowing researchers to capture the overall structure of an entire manuscript at once.

This Card–Deck–Board architecture captures the essential nonlinearity of Flower's model of writing. Schematically depicted in figure 1, it enables researchers to work on multiple aspects of a paper in any sequence, capturing ideas and observations opportunistically as they arise. The sequence and location of cards, as well as the order of decks on a board, can be altered without losing the content of a card; this allows for high flexibility within the given framework structure of a research paper. By embedding nonlinear knowledge capture directly into the research writing process, the proposed system extends the KCIDE philosophy beyond structured problem solving and into the realistic, iterative practice of engineering research.

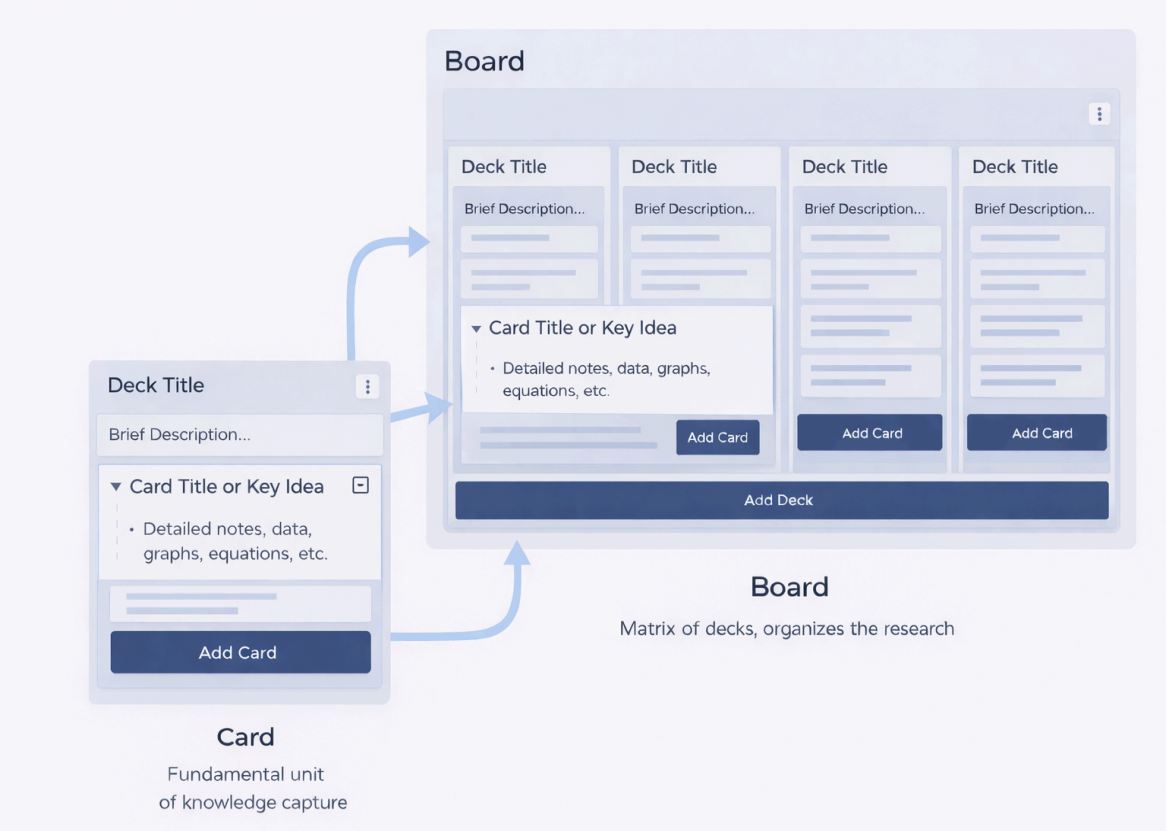
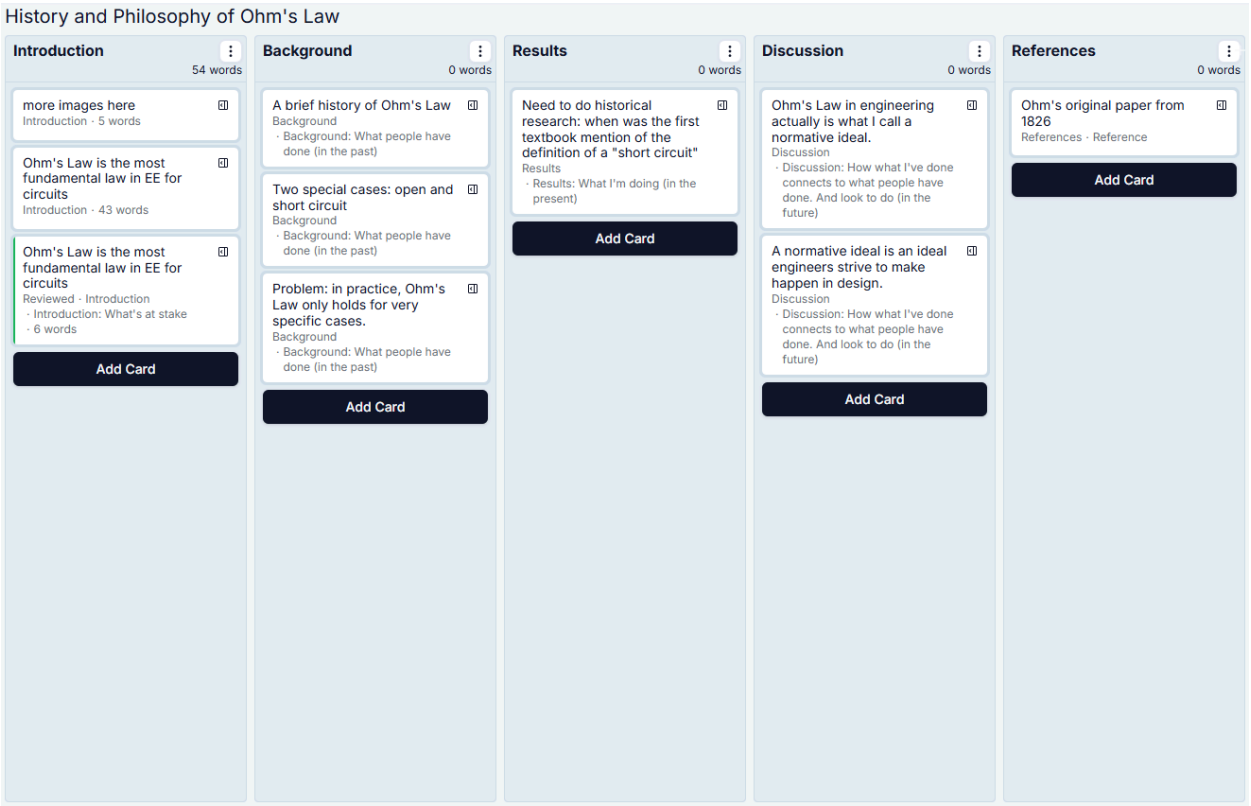


Figure 2: Schematics of the Knowledge Capturing Environment

The proposed knowledge-capturing environment has been implemented as a working digital

platform within NovelPad, a cloud-based writing software designed to support modular, non-linear organization of writing content. The implementation leverages NovelPad's underlying modular flexible architecture to provide persistent, online storage of Cards, Decks, and Boards. This allows researchers to capture and reorganize knowledge continuously over extended research timelines. Unlike desktop-based environments, the platform supports real-time, multi-user collaboration, enabling multiple authors to contribute concurrently to the same research workspace while preserving individual revisions and structural changes. The latter feature allows STEM researchers to document experimental notes, literature insights, and evolving arguments as discrete, movable knowledge units, while simultaneously developing manuscript text within a shared environment.

The following is a screenshot of a sample paper-in-progress on the history and philosophy of Ohm's Law. It shows the card-deck-board concept. More cards can be added to each deck, while each card's position can be shifted anywhere within the entire board.



Discussion and Future Work

While the proposed knowledge-capturing environment addresses key challenges of STEM research and writing, it also presents important limitations that ought to be evaluated during real-world deployment. The effectiveness of a nonlinear, card–deck-board based environment

depends in part on users' familiarity with modular writing and digital knowledge management practices. Without appropriate instructional scaffolding, the flexibility of the environment could potentially introduce organizational overhead rather than reduce it. Furthermore, as with many collaborative, online platforms, the system's effectiveness will depend on external factors such as software stability, network reliability, institutional data policies, and user access to compatible devices. While these considerations are common to contemporary cloud-based tools, they nonetheless affect adoption in educational contexts.

Despite these limitations, the proposed framework is intentionally designed to be domain-agnostic and transferable across STEM disciplines. The Card–Deck–Board architecture does not encode discipline-specific content or methodologies; instead, it provides a structural scaffold for organizing ideas, evidence, and arguments at varying levels of abstraction. As a result, the environment is applicable not only to engineering research writing, but also to interdisciplinary research, proposal development, and technical documentation. The system is particularly well suited to contexts where writing and research progress evolve in parallel over extended periods. These include graduate thesis proposal and dissertation writing, multi-author journal papers, and long-term research projects involving iterative documentation of problem statements and methodologies. Because the environment supports continuous reorganization without loss of content, it accommodates shifts in research direction that are common in exploratory work.

Planned current and future deployments include the use of the platform in graduate-level engineering courses focused on research methods and thesis writing. In this setting, the environment will be used to support literature review development, research proposal formulation, and early manuscript drafting. Such a try-out deployment will provide an opportunity to examine how nonlinear knowledge capture affects graduate students' ability to articulate research frameworks, manage literature, and revise arguments over time.
Planned evaluation will accompany initial classroom deployments. An anonymous online survey will be distributed via the course management system at the end of the term, ideally after grades have been assigned. The survey will include short Likert-scale items on perceived ease of use, usefulness for organizing literature and arguments, and support for revision and collaboration, as well as open-ended prompts (e.g., "Which features most helped you manage sources and ideas?" and "What aspects of the workspace created friction or confusion?"). These data can subsequently be used to refine the interface and instructional scaffolding before conducting a more rigorous study of learning and writing outcomes.

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