Structural Interaction: Shifting the Focus of User Interface Design

Vincent Cavez
Stanford University
USA
vcavez@stanford.edu

Kashif Imteyaz
Northeastern University
USA
imteyaz.k@northeastern.edu

Abstract

The structure of a user interface defines the organizational layout and manipulability of its content. While structure is essential to perform many tasks, such as sorting data in a spreadsheet, its persistent enforcement can be source of conflict when it misaligns with users' mental models. Despite numerous efforts toward more flexible interactions, each tool presents unique challenges and requires situated solutions, making it difficult to establish generalizable design guidelines. This article introduces Structural Interaction, a systematic framework that puts structure's behavior at the center of design considerations. We define structural states as a concept to help designers determine which interactions benefit from structure and which are hindered by it - and to what degree. We demonstrate how designing interactions through this lens can support complex workflows across educative, productive, and creative contexts, both in individual and collaborative settings. Finally, we make recommendations for designing user interfaces with this model.

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1 Introduction

Traditional interface design paradigms frequently default to singular, continuously enforced structural frameworks—rigid organizational schemes that govern all user interactions uniformly. Consider the omnipresent grid structure in spreadsheet applications or the linear slide progression in presentation software. While such monolithic structures provide consistency and predictability, this paradigm fundamentally constrains interaction possibilities and fails to accommodate the diverse cognitive and operational requirements that emerge across different tasks, users, and contexts. The enforcement of a single structural model creates friction when user intentions diverge from the predetermined organizational logic, forcing users to either conform to the system's constraints or seek external tools that better align with their mental models and workflow requirements.

The limitations of singular structural enforcement become particularly evident when examining complex interaction scenarios. Creative professionals require fluid transitions between structured and unstructured exploration; learners benefit from scaffolding that progressively adapts to their developing expertise; collaborative teams need shared frameworks that simultaneously support individual agency and collective coherence. These diverse requirements cannot be adequately addressed through binary approaches that simply toggle structure on or off. Instead, the relationship between structure and flexibility exists along multiple continuous dimensions, with numerous intermediate states that offer varying degrees of constraint, guidance, and user control. Each departure from rigid structure introduces distinct interaction possibilities and design challenges, necessitating careful consideration of how users navigate between different structural configurations.

This paper introduces Structural Interaction as a systematic framework [4] that positions structural behavior as the central organizing principle for interface design. Rather than treating structure as a fixed property of interfaces, we conceptualize it as a dynamic, multidimensional design space that can be deliberately modulated to align with user needs and contextual requirements. Our framework identifies ten distinct structural states—from enforced to freeform—each characterized by specific behavioral properties along five key dimensions: temporal persistence, spatial scope, rigidity, agency, and visibility. This taxonomy emerged from an affinity diagramming of contemporary commercial tools, revealing consistent patterns in how successful interfaces mediate the tension between structural constraint and user flexibility. Structural Interaction fundamentally reframes the design process by shifting the focus from direct manipulation of domain objects [3] to interaction through appropriate structural states. Each state represents a distinct configuration of how users engage with content, progressively relaxing or transforming the initial interface structure to enable different types of activities. For instance, an "elastic" structure provides magnetic guidance that yields to sustained user intention, while a "negotiated" structure allows users to temporarily push against constraints without achieving complete redefinition. These states are not merely theoretical constructs but observable patterns implemented across successful digital tools, from creative applications that blend structured and freeform spaces to learning environments that adapt scaffolding based on user progression.

By providing designers with a principled vocabulary and analytical framework for reasoning about structural flexibility, this work enables more deliberate and effective design decisions. Rather than approaching each new interface challenge as an isolated problem requiring novel solutions, designers can leverage our framework to identify appropriate structural configurations, understand their implications for user interaction, and systematically evaluate tradeoffs between constraint and flexibility. We demonstrate the practical application of this framework through analysis of four exemplar systems across learning, productivity, creativity, and collaboration

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contexts, revealing how thoughtful structural design enables interfaces that are simultaneously powerful and flexible, structured and adaptable, consistent and responsive to diverse user needs.

2 Related Work

Our research approach builds upon established theoretical frameworks in human-computer interaction while extending contemporary understanding of how structural flexibility can be systematically designed to align with diverse user needs and contexts. This work contributes to ongoing efforts in malleable interfaces, instrumental interaction, and adaptive system design.

2.1 Building Digital Structures to Match the User's Cognitive Model

Direct Manipulation Interfaces represent a fundamental paradigm in human-computer interaction where users interact with digital objects through physical, spatial actions rather than through command languages or abstract syntax [27]. This paradigm leverages users' existing mental models of physical interaction to reduce cognitive load and improve usability.

Norman's foundational work demonstrated that mismatches between user expectations and system behavior create fundamental usability barriers, establishing that effective interface design requires explicit consideration of users' existing cognitive structures [47]. Building on this foundation, Beaudouin-Lafon's instrumental interaction model provides systematic frameworks for post-WIMP interface design that leverage users' existing cognitive models of tool-mediated interaction [3].

Recent empirical investigations reveal critical tensions between structural flexibility and cognitive compatibility. Chalhoub and Sarkar's analysis of spreadsheet usage patterns demonstrates how users value the freedom to structure data according to individual cognitive models, revealing complex networks of constraints including user expertise and collaborative requirements [15]. This work highlights the fundamental challenge of designing systems that are both structured enough to be functional and flexible enough to accommodate diverse mental models.

Extending this understanding, Mackay and Beaudouin-Lafon's interaction substrates introduce frameworks that combine structural sophistication with interface simplicity [39]. These substrates function as environments where users maintain control over organizational relationships while accessing sophisticated capabilities. Similarly, Maudet et al.'s investigation of graphic design workflows identified complex "graphical substrates" that designers use based on properties extracted from concepts, content, and context [40]. These substrates serve as flexible organizational frameworks that adapt to creative workflows while maintaining essential structural properties.

Complementing these substrate approaches, previous research has focused on adaptive systems that dynamically respond to individual cognitive patterns. Seminal work on mixed-initiative interfaces demonstrates how automated capabilities can be integrated with direct manipulation while preserving user agency [25]. Advanced user modeling approaches based on cognitive load theory systematically adapt to individual motor and visual capabilities, showing significant improvements in task completion and user satisfaction [19]. Studies of cultural adaptability in user interfaces provide empirical evidence for the benefits of culturally-aware design approaches that account for systematic variations in cognitive models across diverse user populations [49].

Machine learning approaches to predictive modeling of user behavior and preferences represent promising directions for creating digital structures that continuously evolve to match individual cognitive models [20, 43, 44]. However, these approaches primarily focus on adapting existing structural paradigms rather than fundamentally reconsidering how structure itself might be designed as a flexible, multidimensional property.

Critical analyses reveal important limitations in contemporary cognitive compatibility strategies. Norman's examination of gestural interfaces demonstrates that superficial mimicry of physical interaction patterns often introduces rather than reduces cognitive overhead [48]. While computational models can predict user performance and automatically adapt interfaces, systematic attention to conceptual clarity remains essential [19]. However, successful cognitive-structural alignment requires more than surface-level adaptation.

These limitations in contemporary cognitive compatibility approaches motivate our focus on structural interaction as a more nuanced framework. Rather than treating structure as a binary design choice or focusing solely on adaptive algorithms, we propose understanding structure as a multidimensional design space that can be systematically modulated to match diverse user needs and contextual requirements.

2.2 Malleable and Adaptive Interfaces: Toward User-Customized Structure

We view *compositional structures* as the primary *substrates* of interaction, in the sense of Instrumental Interaction, where users act on domain objects through instruments that expose structure for manipulation and recomposition [3]. Treating structures as substrates makes the interface itself an editable medium rather than a fixed container, which aligns with the broader agenda of malleable software and end-user tailoring [33]. At the level of everyday work, users still juggle multi-step, multi-tool workflows, and the traditional application-centric model fragments structure across apps and file types, producing switching costs and coordination overhead [64]. Recent research shows how conceptual blending can flexibly integrate example structures into work-in-progress UIs, blurring the line between design and development [37].

Another approach emphasizes user-side malleability, arguing that interfaces should dynamically evolve to reflect the user's task structure [9]. In this vision, the system generates custom UIs from a high-level task model expressed in natural language, composes a workspace around that model, and allows users to directly edit the underlying structure through prompts or manipulation, which causes the interface to reconfigure in real time. This approach treats the task model as the central artifact and the interface as a malleable projection of it, enabling highly personalized and integrated workspaces. This vision resonates with the *gulf of envisioning* identified by Subramonyam et al. [53], which describes the challenge between a user's initial intentions and the precise natural language prompt needed for an LLM to deliver the desired interface. Whereas the gulf of envisioning highlights the difficulty of specifying intent in natural language, [10] argues for freeform canvases and end-user customizable structures to support exploration and parallel composition within unified workspaces, thereby reducing navigation costs when multiple structures must co-exist.

Pattern-specific work shows how to operationalize malleability within concrete UI idioms. [41] analyze the overview–detail pattern and surface three malleability dimensions: content, composition, and layout. They then provide end-user controls such as Fluid Attributes that let people surface, hide, and manipulate attributes across overview and detail, including AI-assisted transformations.

Together, these threads position interface structure as something to be learned, projected, and reshaped. System-side models reduce fragmentation by adapting structure to the person. User-side malleability empowers direct control over the substrate. Pattern-level toolkits demonstrate concrete mechanisms that make structure visible and editable in situ. Lu et al. [37] illustrates how blending example structures into in-progress work can further expand this design space. This synthesis motivates our focus on interfaces that allow users to work with structure directly, rather than working around it.

2.3 Research Gap

Despite these advances, existing work lacks a systematic framework for understanding when and how different structural behaviors should be applied across diverse contexts and user needs. Our structural interaction model addresses this gap by providing designers with a principled approach to reasoning about structural flexibility as a continuous, multidimensional design space rather than a binary choice.

3 The Role of Structure Across Domains

Structure serves fundamentally different roles across interaction contexts. In productivity, it optimizes efficiency; in creativity, it balances constraint with flexibility; in learning, it scaffolds knowledge acquisition; and in collaboration, it coordinates multiple actors. These contexts often overlap yet impose distinct, sometimes conflicting, requirements. A structure optimized for productivity may hinder creativity; scaffolds for novices may constrain experts. The following sections examine how structure functions in each context, revealing that effective structure must be carefully calibrated to specific tasks, user expertise, and situational dynamics.

3.1 Learning

Learning environments present a particularly delicate balance, especially when considering younger learners. Children demonstrate remarkable adaptability and creative potential, yet their limited attention spans and developing executive functions require carefully scaffolded environments with clear milestones and achievable goals. Research shows that novice learners have constrained working memory and fewer schemas, making them especially vulnerable to cognitive overload during an unstructured learning approach [32]. The challenge lies in providing enough structure to maintain focus and prevent cognitive overload, while preserving sufficient openness for exploration and discovery [63].

Cognitive Load Theory and research on scaffolding both underscore the importance of structured support for novice learners [55, 60]. Cognitive Load Theory highlights the limits of working memory, showing how effective instruction reduces unnecessary cognitive demands while managing task complexity to support schema construction [55] Scaffolding complements this by providing temporary support that enables learners to perform tasks just beyond their current ability; as competence develops, these supports are gradually withdrawn, shifting responsibility to the learner [60].

Even in highly structured learning contexts, it is possible to give learners freedom to personalize and explore without undermining the underlying structure [23]. This way, learners can engage with and personalize the material while the structure remains intact, serving as a stable scaffold that supports exploration and interpretation without constraining it.

Yet even within this formal framework, dynamic elements emerge through features like playback functionality, where the static structure transforms into a temporal experience [46]. Such an approach becomes an interactive interface between structured knowledge and experiential learning. This reveals how learning environments must manage competing cognitive demands: learners need stable reference points to organize their understanding, but also require space to experiment, make mistakes, and develop personal meaning [23]. The investment of attention in learning contexts thus becomes a careful allocation of cognitive resources [18], similar to how educational scaffolding gradually shifts cognitive load from external supports to internal capabilities [60]. Students must internalize existing structures while simultaneously finding creative spaces within or beyond those structures.

3.2 Productivity

Structure plays a dual role in productivity. For novices, it serves as a cognitive support, reducing the mental overhead of decision-making and allowing focus on execution [60]. Templates, workflows, and predefined processes eliminate the need to repeatedly solve organizational problems, freeing cognitive resources for the actual work. This aligns with cognitive load theory: by offloading structural decisions to external frameworks, users can dedicate their limited working memory to the task at hand rather than meta-level planning [56].

However, the relationship between structure and productivity is not always linear. As expertise develops, rigid structures can become constraints rather than enablers. An expert developer might find templates limiting when prototyping novel solutions. A seasoned writer might not prefer prescribed document structures when crafting unconventional narratives [29]. This suggests that optimal productivity requires either adaptive structuring [50], systems that can modulate their level of constraint based on user expertise and task demands, or mechanisms enabling advanced users to bypass structural constraints [42, 50].

Beyond complexity, investment of attention also represents a critical consideration [16]. Structure should minimize attention spent on routine decisions while maximizing attention available for value-generating activities [16]. For novices, this means comprehensive scaffolding that guides each step. For experts, it means minimal, optional structures that can be invoked when needed but don't impose unnecessary cognitive switching costs [36]. However, the most productive systems should also allow users to fluidly transition between structured and unstructured modes, leveraging templates during routine phases while seamlessly shifting to an unconstrained exploration during problem-solving phases.

This dynamic structuring reflects a deeper principle: productive systems must balance efficiency with flexibility. Too much structure creates friction, forcing users into suboptimal patterns [26, 36]. Too little structure leads to cognitive overload and decision fatigue. The sweet spot relies not just on user expertise but by task phase, cognitive state, and even time of day. Modern productivity tools increasingly recognize this, offering features like "focus modes" that temporarily increase structure during high-demand periods while allowing more fluid interaction during exploratory phases [36].

3.3 Creativity

Creative work operates under a fundamental tension. It must be productive by delivering meaningful outputs aligned with design goals, while also remaining open to exploration and invention, generating novel and valuable ideas. This contrasts with efficiency-driven tasks, where both the process and the outcome are predetermined [7, 52].

In many traditional productivity and optimization paradigms, drawing from project management and algorithmic scheduling, the goal is often framed as identifying the most efficient route or minimum-cost solution between starting and ending points (A to B) [57], creative productivity requires what we might call a 'structured wandering,' or constrained exploration within conceptual spaces. This idea aligns with Boden's framework of Creativity [7]. Combinational creativity relies on efficiency in accessing and linking diverse knowledge stores, but also on the flexibility to make unexpected connections. Exploratory creativity demands systematic navigation of conceptual spaces while remaining open to discovering uncharted possibilities within them. Transformational creativity requires both the discipline to understand existing constraints and the flexibility to move beyond them [7].

Such efficiency and flexibility in creative work create unique cognitive load challenges that distinguish it from linear, execution-focused tasks [6, 31], where productivity allows cognitive resources to concentrate primarily on execution [61], creative work demands a complex distribution of attention across multiple, simultaneous cognitive operations [34]. The mind must maintain active awareness of the problem space, constraints, and goals while simultaneously engaging in exploratory activities, testing novel combinations, navigating through conceptual possibilities, and evaluating potential pathways [7].

This exploratory work happens in parallel with continuous evaluative processes that assess not only whether something is new or surprising, but also whether it holds value and relevance within its intended context [8]. The cognitive load required here involves constantly switching between holding stable mental models and actively disrupting them, between preserving existing knowledge structures and deliberately seeking their transformation. This reveals that the structure of creativity isn't simply "unstructured exploration" but rather a dynamic oscillation between convergent and divergent modes of thinking.

3.4 Collaboration

Collaboration brings together productivity, creativity, and learning, blending the demands of each domain while adding new layers of complexity [17]. In most collaborative contexts, teams can generate numerous ideas or outputs, but without mechanisms for convergence and coordination, individual contributions may fail to coalesce into meaningful results [59]. Once again, structure plays a critical role here, providing shared frameworks such as templates, workflows, or conventions that guide joint activity, reduce coordination costs, and support the alignment of effort across team members.

This need for structure becomes particularly evident in making collaboration succeed, where teams must coordinate across multiple roles and skill sets [1, 35]. Research found that data science projects require collaboration between technical team members (data scientists and engineers) and non-technical members (domain experts, managers, and communicators), each bringing distinct expertise to different phases of the workflow [65]. Such exploratory collaborative work across fields, from scientific research to design innovation, requires structural frameworks that balance formal methodologies with the domain knowledge and contextual understanding that reside within different team members' expertise and situated knowledge.

The challenge lies in determining which structural elements should be fixed versus flexible. In collaborative contexts, the underlying structure typically must remain consistent across participants to preserve coherence and prevent conflicts. Individual team members may negotiate their personal interaction with these shared frameworks, but the core structure should provide stable reference points for collective work. As Muller and Weisz [45] show through their analysis of complex organizational applications, successful collaboration often depends on having clear structural frameworks that all participants can rely upon.

Importantly, collaborative structure need not be fully adaptive or malleable. While the CHA framework demonstrates how human-AI systems can involve *"dynamic shifts and exchanges of human and AI initiative"* [45], the structural foundation for collaboration should remain relatively stable. The goal is not to allow the system to continuously reshape itself based on user behavior, but to provide a consistent foundation that facilitates both divergence and convergence within a team. This stability is essential for managing what research describes as the complex collaborative practices that span multiple workflow stages and involve stakeholders with vastly different technical backgrounds [65].

Structure in collaborative contexts thus serves as the essential medium through which collective learning, productive effort, and creative exploration can be coordinated effectively. This must therefore be integrated as an additional constraint, requiring careful articulation with the pre-existing challenges inherent to these contexts.

4 Structure in User Interfaces

The previous section illustrates how different contexts (educational, productive, creative) and settings (individual, collaborative) entail varying degrees of structural organization. This structural variability can manifest within a single activity depending on the specific task requirements. Establishing appropriate structural interaction is therefore critical to optimize information retention, enhance workflow efficiency, facilitate ideation processes, and support collaborative endeavors. This section presents the process that led to the identification of ten structural states elicited from contemporary digital tools.

4.1 Methodology

This investigation employed affinity diagramming [24] to systematically examine the diverse structural configurations present in contemporary commercial tools. The selection of commercial platforms was strategically motivated by the objective to prioritize generalizability and practical applicability through leveraging existing structural paradigms rather than proposing novel frameworks. This methodological decision ensures user familiarity while capitalizing on established interaction patterns that users have already internalized through prior technological engagement.

Affinity diagramming was selected due to its established effectiveness in evaluating interactive systems [38] and its capacity to surface emergent patterns through exploratory sensemaking. This methodology enables the systematic discovery of latent structural relationships that may not emerge through predetermined analytical frameworks.

The analytical framework encompassed three primary contextual domains: Learning, Productivity, and Creativity. Within each domain, we identified the principal categories of commercial tools and systematically selected five of the most widely adopted platforms as of 2025, ensuring representativeness and contemporary relevance. The list of commercial tools considered in this study is reported in Table 2. The authors conducted independent observational analysis of each tool's structural characteristics on sticky notes. Subsequently, these observations were systematically organized through iterative clustering processes, from which five structural dimensions were extracted and helped identify the underlying similarities and distinctions among structural implementations. Each emergent dimension was further stratified into discrete levels to enable nuanced analytical categorization.

4.2 Results

The iterative clustering process revealed five fundamental dimensions that characterize how structure manifests and behaves within digital interfaces.

(1) Temporal persistence (momentary → varying → permanent)
(2) Spatial scope (local → both → global)
(3) Rigidity (low → medium → high)
(4) Agency (user → shared → system)
(5) Visibility (hidden → mixed → visible)

Temporal persistence captures the duration of structural enforcement, ranging from momentary interventions that affect single interactions, through varying durations, to permanent configurations that persist across entire sessions. *Spatial scope* delineates the extent of structural influence within the interface, progressing from local effects confined to individual elements, through hybrid implementations where scope varies contextually, to global structures that govern the entire interaction space. *Rigidity* measures the degree of structural enforcement and user override capability, spanning from low rigidity where structure serves merely as suggestion, through medium rigidity offering resistance while permitting deliberate transgression, to high rigidity where structural rules cannot be circumvented. *Agency* identifies the locus of structural control, distributed along a spectrum from user-controlled configurations where individuals determine structural behavior, through shared control involving negotiation between user and system, to system-controlled structures that operate autonomously based on predetermined logic or detected patterns. Finally, *Visibility* characterizes the perceptual presence of structural mechanisms, ranging from hidden structures, through mixed visibility where structure can be partly hidden and partly revealed, to visible structures. These dimensions collectively form an analytical matrix through which structural behaviors were systematically characterized, compared, and sorted in Table 1.

Enforced structure. Enforced structure in digital tools manifests as immutable frameworks where users must operate within rigid, predefined constraints without possibility for modification or circumvention of fundamental organizing principles. Microsoft Excel exemplifies this paradigm through its invariable cell-grid architecture, where data must conform to row-column intersections without alternative spatial arrangements. Learning Management Systems such as Moodle enforce hierarchical course structures with predetermined content organization schemas that cannot be fundamentally altered. Score writing applications like Sibelius and Finale consistently impose the numerous conventions of Western musical notation, requiring users to translate musical ideas through standardized and rigid symbolic systems. Email clients including Outlook and Gmail enforce an identical email protocol structure, dictating header-body composition and threading mechanisms.

Layered structure. Layered structure represents a system where multiple independent structural frameworks operate simultaneously on the same data, each maintaining separate activation states while collectively mediating user interaction through selective engagement. Adobe Photoshop exemplifies this paradigm through its foundational layer system, where pixel layers, adjustment layers, vector masks, and smart objects function as autonomous structural frameworks that users toggle, lock, or modify independently while preserving the integrity of parallel structures. Three-dimensional modeling environments like Autodesk Maya deploy sophisticated layered architectures encompassing viewport grids, object snapping systems, construction planes, and deformation constraints—each structural layer maintaining operational independence while contributing to the comprehensive spatial manipulation framework. Video editing platforms such as DaVinci Resolve orchestrate timeline tracks, color grading nodes, audio mixing buses, and effects chains as discrete structural layers, enabling editors to engage specific organizational systems while temporarily suspending others.

Escapable structure. Escapable structure represents a rigid organizational framework which maintains its integrity while providing

Structural State	Structural Behavior	D1-Temporal Persistence	D2-Spatial Scope	D3-Rigidity	D4-Agency	D5-Visibility
Enforced structure	Structure is immutable and strictly enforced.	Permanent	Global	High	System	Visible
Layered structure	Multiple immutable structures coexist and are selectively engaged.	Varying	Global	High	User	Visible
Escapable structure	Structure is immutable but can be temporarily bypassed.	Momentary	Global	High	User	Visible
Elastic structure	Structure temporarily relaxes but does not deactivate.	Momentary	Local	Medium	User	Mixed
Suspended structure	Structure temporarily deactivates based on detected user intent.	Momentary	Local	Medium	System	Hidden
Adaptive structure	Structure automatically evolves with use.	Varying	Global	Medium	System	Mixed
Negotiated structure	Structure can be relaxed or deactivated but not redefined.	Varying	Local	Medium	Shared	Mixed
Malleable structure	Structure can be redefined.	Varying	Global	Low	Shared	Mixed
Optional structure	Structure can be invoked on demand.	Varying	Both	Low	User	Hidden
Freeform structure	No structure can be invoked.	Permanent	Global	Low	User	Hidden

Table 1: The 10 structural states along with their associated structural behavior and dimension levels, elicited from the affinity diagramming. Levels are color-coded from light blue to dark blue to emphasize their order along each dimension.

temporary bypass mechanisms, allowing users to briefly escape mandatory constraints before automatic reassertion. Google Docs manifests escapable structure through its HTML source view, permitting users to temporarily circumvent the WYSIWYG editor's formatting constraints to directly manipulate underlying markup before returning to the structured document interface. Microsoft Excel, although enforcing structure for most functionalities, sometimes allows users to momentarily escape it. For instance, the "Paste Special" functionality temporarily bypasses formula dependencies and cell formatting rules to insert raw values before reintegration into the relational matrix. Project management platforms like Asana implement quick-add mechanisms that bypass standard workflow hierarchies, allowing task creation outside established project structures before automatic categorization processes restore organizational coherence. Presentation tools like PowerPoint and Keynote provide presenter view modes that temporarily escape the linear slide progression, enabling non-sequential navigation during live presentations while preserving the underlying structural sequence.

Elastic structure. Elastic structure provides magnetic guidance through soft constraints that locally bend under sustained user action while immediately restoring when interaction stops. Adobe Premiere Pro exemplifies this principle through its timeline snapping mechanism, where clips magnetically align to edit points and markers yet permit frame-precise positioning through continued cursor movement, establishing a negotiated relationship between structural suggestion and editorial precision. Figma's smart alignment guides demonstrate elastic structural properties by generating dynamic visual indicators and magnetic attraction zones that propose optimal spatial relationships while permitting deliberate override through sustained manipulation. Presentation platforms like Google Slides also manifest elastic structure via object alignment guides that create temporary magnetic fields around symmetrical positions, bending spatial freedom toward organizational coherence without enforcing absolute compliance.

Suspended structure. Suspended structure automatically relaxes constraints during active user interaction and reasserts them when interaction pauses. Google Docs demonstrates this pattern through its grammar checking system that suspends error highlighting during rapid typing, then reasserts checking when typing stops to avoid disrupting writing flow. Similarly, Slack implements suspended structure through its markdown rendering, which suspends formatting during message composition and only processes formatting when the user sends the message. Microsoft Word suspends its auto-formatting rules during continuous text entry, then reasserts these rules at paragraph breaks or when typing pauses. Learning platforms like Moodle suspend answer validation in quiz interfaces during rapid response entry, then reassert validation when the user pauses or submits, preventing premature error feedback that disrupts problem-solving.

Adaptive structure. Adaptive structure automatically evolves through user interaction, progressively modifying its constraints, affordances, and complexity based on detected patterns of use, expertise development, or pedagogical objectives. This evolutionary paradigm manifests distinctly in adaptive learning platforms like Smart Sparrow and ALEKS, which continuously recalibrate content difficulty and instructional scaffolding based on learner performance metrics, progressively revealing advanced concepts while fading supportive structures as competence develops. Similarly, Google Sheets demonstrates adaptive structure through its Explore feature, which learns from user data patterns and progressively suggests more sophisticated formulas, visualizations, and analytical approaches based on detected usage patterns and data complexity. Notion exhibits adaptive structural properties by progressively revealing advanced database features and template suggestions based on user engagement patterns, transforming from simple note-taking to complex knowledge management as user expertise grows.

Negotiated structure. Negotiated structure represents a framework where users actively push against predefined constraints through deliberate actions, establishing unstructured zones within rigid environment without achieving structural redefinition. This negotiative paradigm can be seen in Airtable, where users negotiate between spreadsheet conventions and database structures by introducing unstructured text fields, informal tagging systems, and hybrid organizational schemas that push against the platform's relational database structure while remaining constrained by its fundamental grid architecture. Similarly, Notion demonstrates negotiated structure through its flexible block system, where users negotiate between structured databases and freeform content by embedding unstructured text within database entries, creating informal linking patterns that circumvent formal relational structures, and establishing personal organizational conventions that push against but cannot fundamentally alter the platform's block-based architecture.

Malleable structure. Malleable structure is one in which users exercise strong authorial control, enabling them to fundamentally redefine organizational principles and behavioral rules, affecting the entire interface. In its modern sense, true malleability also requires that end-users be able to transform the structure with little to no programming expertise—often with the aid of AI. None of the tools examined in this study fully exhibit this property. Game development engines such as Unity and Unreal Engine approach true malleability, as users can redefine rendering pipelines, rebuild physics systems, and design entirely new interaction paradigms. However, these modifications demand complex scripting. Likewise, Microsoft Excel can approximate true malleability through VBA programming, but only for users with substantial programming literacy.

Optional structure. Optional structure remains inactive until explicitly invoked by user action. This opt-in structure can be found in Microsoft PowerPoint through its slide master templates and design themes, which users can selectively apply to transform unstructured presentations into structurally consistent documents. Similarly, Obsidian offers optional structure through its graph view and linking systems, where users begin with plain markdown files and consciously choose to invoke relational visualization and backlinking structures. Furthermore, Trello exhibits optional structure through its Power-Up system and automation rules, which remain completely absent until users actively enable these structural extensions, transforming simple boards into complex workflow systems. Adobe Photoshop implements optional structure through its grid systems and ruler guides, which designers must explicitly activate to impose spatial organization onto unstructured canvases. Finally, Discord provides optional structure through its role hierarchies and permission systems, which servers can invoke to transform unstructured chat spaces into formally organized communication channels.

Freeform structure. Freeform structure denotes environments that provide a seemingly unstructured space, without explicit constraints. This paradoxical category is often seen in creative tool initialization states. Blender's empty viewport exemplifies freeform structure through infinite three-dimensional space without default objects, grids, or units, though Cartesian coordinates remain as irreducible substrate. Similarly, Unity's blank scene provides unbounded virtual space lacking predetermined assets or behaviors, while maintaining minimal engine architecture. Note-taking applications like Apple Notes demonstrate freeform structure through unrestricted text entry without formatting requirements or organizational hierarchies, maintaining only sequential character storage. Adobe Photoshop's blank canvas represents freeform structure through undifferentiated pixel space without layers, guides, or compositional constraints, retaining only resolution boundaries. These examples reveal that freeform structure operates as theoretical limit rather than achievable state, with commercial tools approaching but never achieving complete structural absence.

5 Examining Structural Interaction in Four Use Cases

5.1 Learning

Conventional tools for learning mathematics usually involve either an *enforced* structure, such as rigid step-by-step tutorials and automated grading systems, or an *escapable* one, as in Computer Algebra Systems (CAS) where students can bypass the procedural steps to reach a solution directly. On the one hand, systems that rely solely on *enforced* structure ensure correctness and guide novice users, but they often restrict exploration of alternative strategies. On the other hand, systems governed by an *escapable* structure reduce the burden of notation but risk collapsing the learning process into mere answer-checking, thus missing the practice of strategy development. The dominance of these two structural modes leaves a deficit: students are not adequately supported in exploring multiple solution paths, reflecting on their decisions, or comparing approaches with peers.

Beaudouin-Lafon and Xia [5] addressed this structural limitation with a *layered* structure in MathMap, a system designed to help high school students learn algebraic problem-solving through (1) spatial, (2) temporal, and (3) communal exploration (see Figure 1). MathMap makes suggestions and encourages branching by representing each algebraic problem as a Work Tree, where nodes correspond to expressions and edges represent transformations. Spatial exploration supports trying parallel strategies and mapping problems to different solution paths. Temporal exploration enables reflection on how expressions evolve, allowing students to track sub-expressions across transformations and revisit alternative suggestions previously presented by the system. Communal exploration aggregates work trees across a class, enabling both teachers

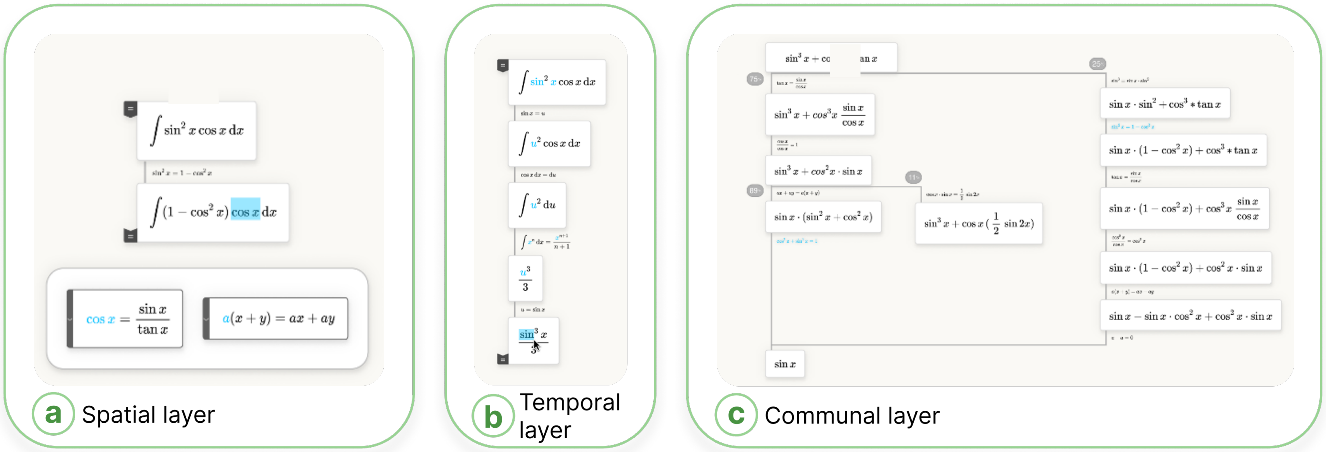

Figure 1: A mathematic learning system introducing a *layered* structure. Adapted from [5].

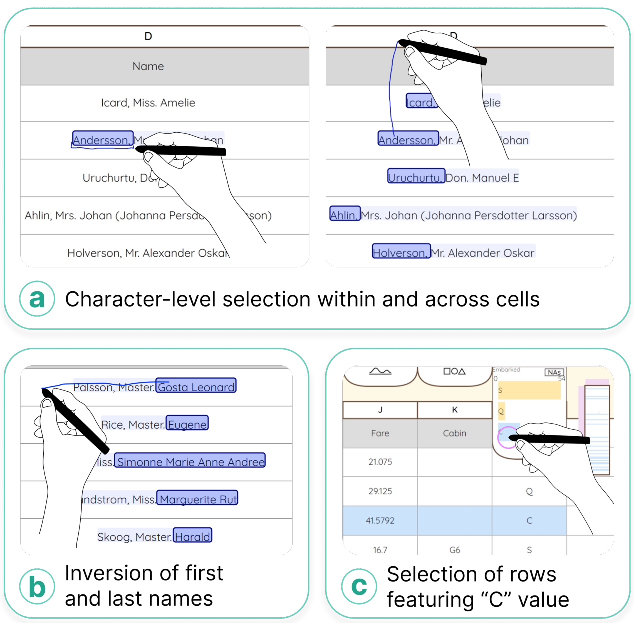

Figure 2: A spreadsheet system reintroducing an *escapable* structure. Adapted from [12].

and students to visualize common strategies, identify pitfalls, and learn from collective problem-solving patterns. MathMap's triadic structure illustrates the benefits of guided correctness while fostering reflective and multi-path learning.

5.2 Productivity

Conventional spreadsheet applications such as Microsoft Excel have an *escapable* structure, which benefits grid-based operations but also enables the temporary circumvention of the grid to promote value editing as well as more advanced operations (see Section 3.2). This structural state constitutes a fundamental characteristic of spreadsheet applications on desktop. However, their migration to interactive surfaces reveals a critical structural limitation: unlike their desktop counterparts, they fail to support *escapable* structure due to input modality constraints and replace it with an *enforced* structure. This produces significant usability friction and precludes numerous essential features standard in desktop tools.

Cavez et al. [12] addressed this structural deficit by reintroducing *escapable* structure through pen-based interaction design. Their approach exploits the superior precision and expressivity of pen input to develop interaction techniques that temporarily bypass grid constraints, such as fluid character-level selection within and across cell boundaries (see Figure 2a), precise character insertion and manipulation operations (see Figure 2b), and content-based row selection replicating complex formula operations (see Figure 2c). The interaction model maintains clear modal separation: finger input and pen tap trigger grid-based operations, while precise pen strokes allow users to reach the values underneath, thereby eliminating mode-switching requirements and interaction ambiguity. Their empirical evaluation supports this approach, demonstrating that differential input modalities can effectively restore the structural articulation inherent to desktop spreadsheet applications.

5.3 Creativity

Score writing applications such as Sibelius and Finale shift between two primary structural states: *enforced* structure, comprising the predetermined notation rules required to produce standardized scores, and *elastic* structure, implemented through magnetic snapping mechanisms that guide element positioning while permitting override through sustained manipulation. The overall interface remains highly rigid and significantly impedes creative exploration, compelling composers to supplement their workflow with unconstrained media such as paper [14].

Cavez et al. [13] addressed this tension in EuterPen by introducing *negotiated* structure, enabling users to temporarily push against structural constraints while maintaining a strong proximity to structure. The system allows composers to create canvas spaces

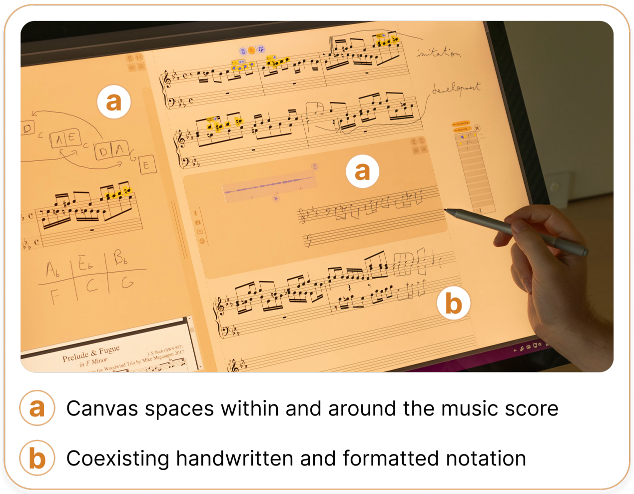

Figure 3: A music score writing system introducing a *negotiated* structure. Adapted from [13].

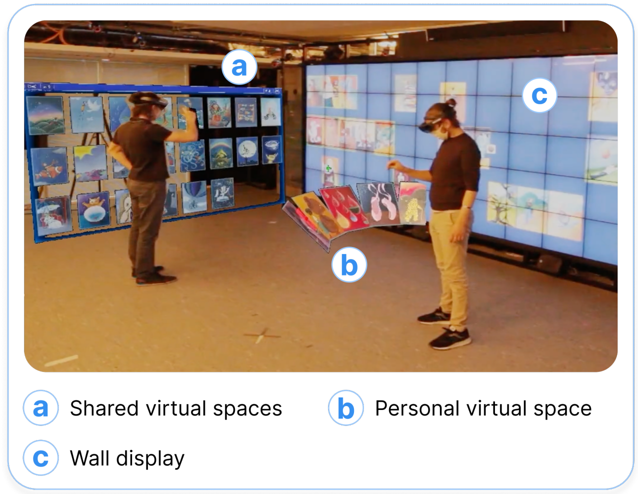

Figure 4: A classification and storytelling collaborative system introducing *optional* and *malleable* structures. Adapted from [28].

within scores where they can explore musical ideas without systematic interference (see Figure 3a). These exploratory spaces can persist indefinitely without forced reversion to structured notation, allowing extended creative exploration. Furthermore, EuterPen enables the coexistence of formatted notation and diverse content such as handwritten notation (see Figure 3b), a capability absent in commercial tools. Flexible and rigid features are carefully integrated. Although handwritten notation appears unstructured, it still enables operational functionality: composers can listen to it, execute pattern searches, and turn it into formatted notation at will. As EuterPen is designed for direct interaction on interactive surfaces, the system replaces the *elastic* structure of desktop applications with *suspended* structure: elements can be manipulated freely without magnetic snapping mechanisms, with adjustments occurring only upon interaction completion. The empirical evaluation revealed that composers identified content stability as a primary usability concern in traditional systems, where automatic formatting adjustments frequently disrupt compositional flow. The *negotiated* structure in EuterPen resolved this tension by enabling contextual experimentation without destabilizing existing content, thereby supporting both creative exploration and workflow stability. This structural approach demonstrates that *negotiated* structure can preserve the benefits of structure while creating freeform spaces for flexible creative work.

5.4 Collaboration

Collaboration leveraging a wall display usually operates through a simple but *enforced* structure for two main reasons. First, collaborators share a unique workspace, and second, input options are limited. This *enforced* structure ensures shared visibility but constrains collaboration by limiting divergence in perspectives, reducing opportunities for personal exploration, and forcing teams to clear or reorganize content when display becomes saturated. As wall displays are static, heavy, and expensive to reconfigure, the sole presence of *enforced* structure often produces friction in collaborative workflows, especially when tasks require parallel exploration or differentiated roles.

James et al. [28] addressed this structural limitation in a Wall+AR system which augments a physical wall display (see Figure 4c) with shared and personal virtual surfaces rendered in Augmented Reality (see Figure 4a,b). The system blends stable common ground — the high-resolution wall — with on-demand extensions that collaborators can create, move, and reorganize around the room. These shared virtual spaces act as *optional* structures for classification, storage, or presentation, while a belt-like personal space provides users with a private *malleable* structure that can be converted into shared surfaces at will. By anchoring all surfaces to magnetic room boundaries, the system maintains spatial coherence while enabling collaborators to dynamically redistribute their work across physical and virtual planes.

Optional and *malleable* structures in Wall+AR transforms collaboration strategies. In classification tasks, pairs of collaborators consistently divided work early by creating separate AR surfaces, shifting toward loosely coupled, parallel activity. In storytelling tasks, pairs maintained tightly coupled collaboration but reallocated their work to AR surfaces rather than clearing the wall, using virtual spaces both as working and presentation areas. The system thus preserved the benefits of enforced common ground while creating structural escape hatches for divergence.

In the empirical evaluation of the system, participants demonstrated higher efficiency, enjoyment, and perceived workspace sufficiency compared to wall-only setups. This structural approach demonstrates that a reconfigurable structure can preserve the stability of enforced shared frameworks while supporting dynamic, multi-perspective collaboration across fluidly shifting tasks and strategies.

6 Recommendations for the Design of Structural Interactions

In addition to the four systems described in detail in the previous section, we conducted a qualitative analysis of 12 research prototypes to identify design patterns that would potentially support flexible interface design. We only selected tools that involved more than a single, *enforced* structure, and were either directly accessible or at least had a video demonstration and accompanying technical description of the features. For each tool, we identified the structural states and the interactions they support. We then clustered the identified features based on their functional similarity to develop a set of interface design patterns for structural interaction. We do not claim a comprehensive categorization but provide a starting point for the design of interfaces using structural interaction.

Design Pattern 1 - Identify the Core Structure: The design of compelling digital tools begins with identifying the core structure of the activity. In certain domains, the core structure presents itself explicitly - spreadsheet applications center on the grid structure [12]. However, structure identification often demands empirical examination of domain practices and user workflows. Griffith's development Kato et al. [30] exemplifies this approach through longitudinal collaboration with anime directors, revealing how storyboard structures integrate scene illustrations, timing information, and textual descriptions in culturally specific ways. Similarly, while music notation tools ostensibly center on the score structure [13], research with nine professional composers [14] uncovered numerous implicit rules and conventions that extend beyond visible notation, influencing how composers conceptualize musical ideas within digital environments. Effective structure identification requires methodological rigor in balancing domain conventions with user mental models. This process represents the first step toward distinguishing operations that necessitate structural support from those that benefit from structural flexibility.

Design Pattern 2 - Align Structural States with Context: Structural states must be selected in accordance with the contextual requirements (e.g., domain of activity, user population, device characteristics, setting), as they play a fundamental role and may conflict with the mental models associated with the activity. As illustrated in Sections 3 and 5, the presence of *layered* [5], *adaptive* [58], and *optional* structures [11, 54] for exploring strategies and accessing additional information fosters learning. Productivity benefits from rich yet efficient interactions supported by *escapable* [12], *elastic* [21], and *suspended* [51] structures. Creativity flourishes when users can rapidly explore ideas within *negotiated* [13], *malleable*, or even *freeform* structures [30, 37]. Collaboration, in turn, is enhanced by a degree of personalization - such as *optional* [62] and *malleable* [22, 28] structures - built on top of a strong shared foundation. However, the effectiveness of these structures ultimately depends on the specific activity and must be determined on a case-by-case basis.

Design Pattern 3 - Be Selective with Structural States: Constraining the number of structural states represents a critical design principle for maintaining cognitive coherence and system learnability. Proliferation of structural states imposes multiplicative cognitive load, as users must not only comprehend individual states but also navigate transitions and maintain awareness of current operational context. Empirical evidence demonstrates that effective systems typically implement selective structural parsimony. EuterPen [13] concentrates creative interactions within a single *negotiated* structure, reserving *escapable* structure exclusively for layout fine-tuning operations. This architectural constraint reduces cognitive overhead while preserving functional completeness. Similarly, systems that successfully implement minimal structural paradigms demonstrate the viability of this approach through comprehensive feature integration within unified frameworks [5, 12]. The cognitive complexity introduced by multiple structural states follows non-linear growth patterns, as each additional state requires users to internalize not only its operational characteristics but also its contextual triggers and transition mechanisms. Systems implementing numerous structural states should therefore target expert user populations with established domain expertise and tolerance for interface complexity [21, 51].

Design Pattern 4 - Align Features with Structural States: Systems with multiple structural states demand precise feature-to-structure mapping based on careful analysis of user workflows and cognitive processes. This analytical requirement intensifies in domains where interaction patterns exhibit greater complexity and variability. In their system, James et al. [28] demonstrate systematic feature-structure alignment through precise mapping of functionality to structural states. The system associates content appropriation and transformation features with *malleable* structure, enabling unrestricted workspace manipulation. Temporary content storage operates through *optional* structure, providing on-demand organizational capabilities without imposing persistent constraints. Final formatting and persistence functions are associated with *enforced* structure, ensuring document integrity and standardization. This tripartite mapping establishes clear operational boundaries between exploratory manipulation, intermediate organization, and final production phases.

Design Pattern 5 - Ensure Stability of the Content: Content stability during structural transitions is essential for user trust and exploratory confidence, especially in learning and creative workflows. EuterPen's [13] empirical evaluation explicitly identifies content stability as composers' primary usability concern, and demonstrated how *negotiated* structure allows contextual experimentation without disrupting existing notation through automatic formatting adjustments. Spellburst [2] addresses stability through node-based branching and merging operations, enabling artists to explore variations while maintaining original content integrity. texSketch [54] preserves reading flow stability while enabling diagram construction through pen-and-ink annotations that don't disrupt the underlying text. These implementations demonstrate that effective stability mechanisms must provide clear preservation guarantees, visual persistence indicators, and reversible operations, enabling users to venture into unstructured exploration with confidence that their core content remains protected and recoverable.

7 Scope and Future Work

Our structural interaction framework opens multiple avenues for theoretical expansion and empirical investigation.

Our five dimensions—temporal persistence, spatial scope, rigidity, agency, and visibility—emerged from analysis of existing tools and may not be comprehensive. Interface technologies continue to evolve, potentially requiring additional dimensions or different characterizations. The discrete levels we identified within each dimension (low/medium/high, momentary/varying/permanent) represent simplifications that may obscure important nuances. Continuous scales might better capture the gradual transitions between structural states observed in practice. Despite these limitations, the framework provides a systematic starting point for reasoning about structural flexibility in interface design.

Additionally, our analysis focused on desktop, tablet, and wall-display interfaces, leaving other interaction modalities unexplored. Future work could examine how the framework applies to mobile interfaces, voice interactions, and virtual reality environments. Additionally, cultural contexts and accessibility requirements may reveal structural patterns not captured in our current taxonomy, as our sample predominantly reflected Western commercial software design.

The framework requires empirical validation to establish whether the proposed structural states effectively support flexibility in user interface design, compared to current practices. While we provide theoretical justification and design examples, dedicated studies are needed to test the framework's predictive validity and practical utility. Such studies could examine whether users benefit from different structural configurations as theorized, and whether the dimensional characterization adequately captures user interface various structures.

8 Conclusion

Our work applies a structural framework to characterize interface flexibility across diverse contexts, highlighting the complexity of designing systems that adapt to varied user needs while maintaining functional coherence. While interfaces require structure to organize information and enable manipulation, rigid paradigms often conflict with users' mental models and task requirements. We identify ten distinct structural states that capture how interfaces modulate their organizational properties, from enforced structures to freeform environments. This structural interaction framework is defined by five key dimensions: temporal persistence, spatial scope, rigidity, agency, and visibility. We provide a systematic guidance for moving beyond binary thinking about structure presence. Our design recommendations offer concrete guidance for implementing structural flexibility. This enables designers to reason systematically about when structure should constrain, adapt, or disappear, providing a principled approach to creating interfaces that serve diverse user needs and contexts.

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A Affinity Diagramming

Context	Category	Commercial tools
Learning	Learning Management Systems	LearnDash, MemberPress, LearnPress, Tutor LMS, *Moodle*
	Learning Experience Platforms	iSpring Learn, Absorb LMS, *TalentLMS*, *CYPHER Learning*, *LearnWorlds*
	Serious Games	DragonBox, *Minecraft Education*, *IBM CityOne*, *Classcraft*, *Markstrat*
	Adaptive Learning Platforms	Smart Sparrow, DreamBox Learning, Knewton Alta, ALEKS, Area9 Rhapsode
	Course Marketplaces & MOOCs	Coursera, Udemy, edX, LinkedIn Learning, Skillshare
	Assessment & Quiz Tools	ClassMarker, *Kahoot!*, *Quizizz*, *Socrative*, *Mentimeter*
Productivity	Spreadsheets	Microsoft Excel, *Google Sheets*, Apple Numbers, *Airtable*, *Smartsheet*
	Presentation Tools	Microsoft PowerPoint, *Google Slides*, Apple Keynote, *Prezi*, *Canva Presentations*
	Word Processing	Microsoft Word, *Google Docs*, Apple Pages, *Notion*, *Dropbox Paper*
	Project Management	*Asana*, *Monday.com*, *Jira*, *Trello*, *ClickUp*
	Note-Taking	*Notion*, *Evernote*, *Microsoft OneNote*, Obsidian, Apple Notes
	Task Management	Todoist, Microsoft To Do, Any.do, Things 3, TickTick
	Calendar and Scheduling	*Google Calendar*, *Microsoft Outlook Calendar*, *Calendly*, Apple Calendar, Fantastical
	Communication and Messaging	*Slack*, *Microsoft Teams*, *Discord*, *Zoom*, *Google Meet*
	Email Clients	Microsoft Outlook, Gmail, Apple Mail, Thunderbird, and Spark
Creativity	Video Editing	Adobe Premiere Pro, Final Cut Pro, *DaVinci Resolve*, Adobe After Effects, Avid Media Composer
	Audio Editing	Ableton Live, Logic Pro, Pro Tools, GarageBand, FL Studio
	Score Writing	Sibelius, Finale, Dorico, MuseScore, Notion 6
	Graphic Design	Adobe Photoshop, Adobe Illustrator, Adobe InDesign, *Canva*, *Figma*
	3D Modeling and Animation	Autodesk Maya, Blender, Cinema 4D, Houdini, ZBrush
	UI/UX Design	*Figma*, *Sketch*, *Adobe XD*, *Framer*, InVision
	Game Development	Unity, Unreal Engine, Godot, GameMaker Studio, Construct 3

Table 2: The 110 commercial tools considered in the affinity diagramming. Collaborative tools are in italic.