L.ink: Procedural Ink Growth for Controllable Surprise

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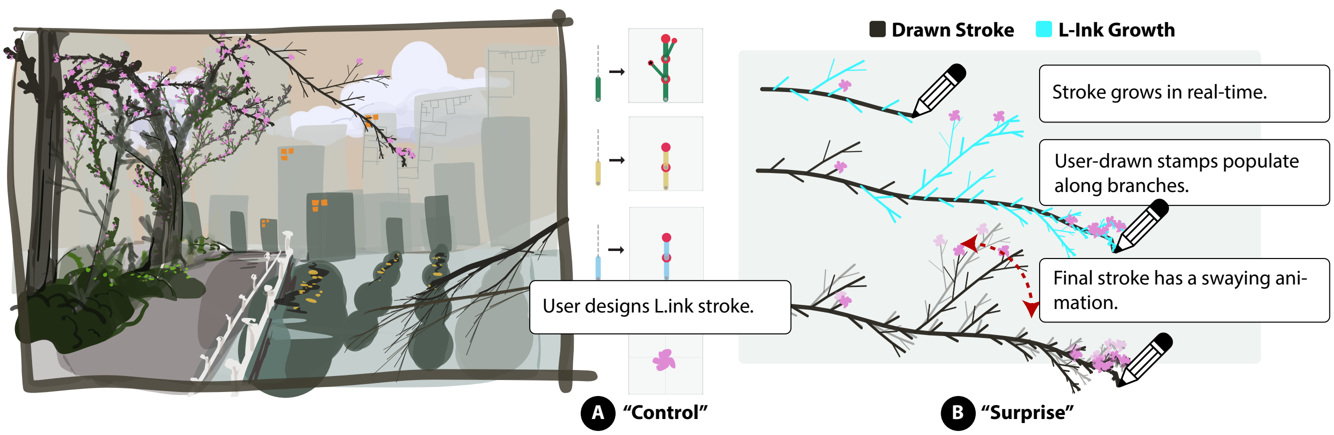

Figure 1: With L.ink, users draw strokes that grow into realistic, animated, branching structures. A: Users *control* ink styles by directly manipulating branch topology, lengths, angles, and custom stamps via a visual rule editor. B: Real-time stroke growth evokes *surprise* within the user, enhanced by procedurally-arranged stamps and animations.

Abstract

Control, a common principle in interface design, helps artists achieve desired outcomes when using creativity support tools. However, surprise also plays a role in creative practice by facilitating introspection and adaptation. Consequently, creativity support tools face the challenge of balancing these two properties. We present L.ink, a digital illustration tool that empowers artists to draw with controllable yet unpredictable procedural growth styles powered by L-systems. Through a formative study of an early prototype of the system, we identify three types of surprise and adapt our design with a direct-manipulation editing interface with live visual feedback and a hand-drawn stamp tool to afford control and mitigate unwanted surprise. We further evaluate how controllable surprise impacts creative workflow and experience through a task-based study with 12 artists. Based on our observations, we extract guidelines for when and how to effectively incorporate unpredictability into creativity support tools.

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CCS Concepts

• **Human-centered computing** → **Graphical user interfaces**; **Web-based interaction**.

Keywords

Creativity Support Tools, Vector Illustration, Procedural Art

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1 Introduction

In the design of creativity support tools (CSTs), *control* enables artists to influence a system according to their will, translating their mental processes into desired outputs. Control is a well-established principle of interface design [50]. At the same time, *surprise*—while at odds with some metrics of usability [5]—also plays a key role in the creative process. Cognitive psychologist Barbara Tversky describes how architectural students inspecting their own sketches react to unexpected features and relations by revising their design ideas, like “having a conversation with one's self” [54]. This is an example of what Schön calls "reflection-on-action," in which discrete periods of action and reflection are interleaved [49]. However, Schön also identifies the distinct practice of "reflection-*in*-action," in which artists allow unexpected stimuli to continuously influence their work on the fly. Infinitesimal moments of surprise trigger in-the-moment thinking, inspiring further action. The reflection-in-action framework suggests that unpredictability may facilitate introspection, adaptation, and evolution of creative ideas.

Drawing, like other art forms, has the potential for surprise. Physical media introduce unexpected variations through the entropy of bleeding ink, interactions with paper texture, and smudging dynamics. Now with digital media, the range of possible unpredictable effects is vast—from simple physical simulation [1] to living strokes that meander across the screen when the artist takes a break [31]. By engineering unpredictable effects, these tools have the potential to transform the illustrator's experience of reflection-in-action. Of course, simply maximizing surprise would make illustration tools unusable—some degree of control is necessary. The tension between surprise and control suggests a fruitful area of investigation.

In exploring this tension, we can observe that unpredictability and determinism are not mutually exclusive. Lindenmayer systems (L-systems), parallel rewriting systems that generate organic growth, exhibit unpredictability in a fully deterministic way [32]. Their balance of order and disorder generates effective complexity [14]. Given a simple set of rules, L-systems generate emergent structures which appear intricate and random, yet the same rules always produce the same structures. This property implies that users could customize L-system rules with full control, yet still experience surprise upon visualizing the resulting structure. Motivated by this line of reasoning, we reimagine L-systems as artistic media, designing a CST as a probe [30] to study controllable surprise.

We present the following contributions: **First**, we introduce *L.ink*, a digital illustration tool empowering artists to draw with controllable yet unpredictable growing ink powered by the L-system representation (see Figure 2 for example outputs). Strokes grow into intricate branching structures in real-time to enhance the natural unpredictability of L-systems and contribute to in-the-moment engagement through surprise. On the other hand, a direct-manipulation rule-editor with a live preview allows users to precisely control parameters to edit ink styles. **Second**, we conduct a formal evaluation with 12 artists demonstrating how controllable surprise impacts artist engagement, workflow, and output. We report findings suggesting that our system encourages experimental flow towards creating diverse artistic outputs. **Third**, we provide recommendations for when and how to incorporate unpredictability into CSTs.

We previously introduced the first contribution (the L.ink system) in a CHI Late-Breaking Work [6]. Our second and third contributions are new to this paper, significantly expanding on this foundation by evaluating our system's impact and presenting generalizable insights for CST design.

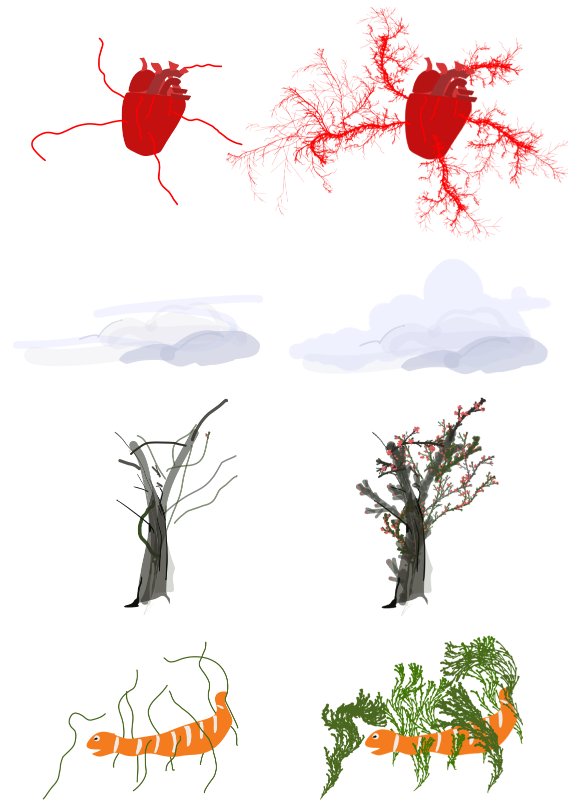

Figure 2: Comparison between sketches without L.ink growth (left), and with L.ink growth (right). Users can generate realistic and expressive organics with only a few strokes.

2 Related Work

2.1 Alternative CST Lenses

Many prior works have explored alternative ways of designing and evaluating CSTs beyond traditional usability. Greenburg and Buxton [16] argue that usability evaluation should be applied when warranted on a case-by-case basis, rather than as a rule. Kim et al. [27] propose designing CSTs that intentionally support failure to create a safe space for novice experimentation. J. Li et al.[30] and I. Li et al. [29] argue for the importance of designing flexible, appropriable tools in order to provide "power-to" rather than exert "power-over" users. As we will discuss later, our findings contribute back to this conversation by exploring how users negotiate power with a generative medium that exerts a "will" of its own.

Of particular relevance to L.ink, The No-input Mixing Desk [35] is a digital tool designed to explore how musicians interact with auditory feedback loops. Findings from this work highlight unpredictability as a key feature contributing to enjoyment and creative gratification. L.ink explores unpredictability in the domain of digital illustration, building on The No-input Mixing Desk by offering guidelines for mediating surprise with control and recommendations for when and when not to incorporate surprise—including axes of beginner vs. expert, ideation vs. final product phase, and abstract vs. concrete art. We return to this point in the Discussion.

2.2 Augmented Illustration

Digital illustration provides opportunities to augment the drawing process with computation, enabling experiences and outcomes impossible with traditional media. Computational augmentation fulfills a range of functions. CAD/CAM systems like SketchPad [53] provide enhanced precision by specifying exact constraints. Other systems enable extrapolating 2D sketches to 3D models [3, 8] or allowing sketches to be associated to external data for visualization [28, 37, 57]. Still another class of augmented illustration involves computationally simulating physical media like watercolor, oil paint, or bleeding ink [9, 12], combining realistic physical media with the convenience of digital erasure and undo operations.

Digital illustration tools also enable drawing with new, imaginative materials. For example, in Vignette [26], users draw with repeated patterns like fish scales, hair, or vegetation by duplicating fractional examples drawn by hand. Other works extend this idea by allowing strokes to represent *dynamic* materials as well. Draco [25] and Kitty [24] allow drawing kinetic textures of object collections like waving tree leaves or a swimming school of fish. Energy Brushes [58] enables drawing with energy strokes that drive dynamic movement of user-drawn materials like fire and smoke. Filtered.ink incorporates dynamic textures directly into the user's ink, eliminating the need for post-hoc control strokes and demonstrating smoother integration into artists' drawing processes [60]. Para [23] and Dynamic Brushes [22] also explore integration of procedural tools into manual practice—Dynamic Brushes enables programmable brushes with a block-based visual editor while Para uses a duplication paradigm with declarative constraints to enable complex compositions of multiple shapes. Finally, Neural Brushstroke Engine [51] uses data-driven deep learning methods to allow users to generate brush textures with natural language descriptions like "lady bug" or "blades of grass."

L.ink builds on the foundation set by procedural brush systems like Filtered.ink [60] and Dynamic Brushes [22], which combine brush programming and freeform drawing. While these systems' broad goals of manual-procedural integration lead to open-ended designs, L.ink probes one specific aspect of manual-procedural creation—micro-scale interactions between the artist and procedural emergence—by limiting its scope to L-systems. This enables unique findings around the interplay between controllability and surprise. In comparison to compositional tools like Para, [23] L.ink's gestural brush model is specifically designed to investigate how artists interact with micro-scale, continuous surprise, where reflection-in-action occurs.

2.3 Interactive Growth Models

L-systems are procedural models that generate organic branching geometry, typically representing plants [32]. Formally, an L-system is specified by a starting symbol called the axiom and a set of textual substitution rules of the form $A \rightarrow B$, which indicates that the symbol A should be replaced with the string B at each iteration. L-system generation occurs in two phases: a *growth phase* and an *interpretation phase*. In the growth phase, we begin with the axiom symbol and repeatedly transform it by applying the substitution rules in parallel, deriving a longer string with each iteration. In the interpretation phase, the derived "L-string" is mapped to geometry by sequentially reading symbols as "turtle graphics" commands [47]. Standard L-systems as described above are fully deterministic, yet produce complex, organic-looking structures.

Since their conception, L-systems have evolved to incorporate various forms of user interaction. Early developments included real-time visual feedback while tuning L-system parameters [43–45], conditional rule application depending on live user interaction [17, 40], and post-hoc branch repositioning [46].

Of particular relevance are interfaces where 3D drawing (gestures) or 2D drawing (sketching) directly guides the progression of an L-system's growth. Onishi et al. developed a system in which 3D hand position interactively generates a trunk which can later be interactively grown into a branching structure [41]. The Sketch L-System [21] introduces a method for 3D L-system generation by 2D sketching using a special symbol whose geometric interpretation depends on the user's pen position. Drawing a stroke advances the L-system growth iteration-by-iteration with real-time visual feedback. L.ink extends the foundational ideas of this work, and differentiates itself by (1) supporting 2D illustration rather than 3D modeling—a distinct practice with different users, (2) allowing segments to bend as guided by the user's pen, which make L-systems a flexible drawing medium accommodating abstract, non-botanical effects, (3) introducing hand-drawn stamps tailored to 2D illustration. (4) supporting animation, and (5) supporting addition/removal of branches so users can create any rule definable with symbols. As we will see in the Results section, these features empower users to create a wide range of divergent styles.

Other interactive growth systems utilize a variety of models besides L-systems, including hierarchical structure-graphs [11], self-organizing models [33, 42], Markov random fields [7], a foliage spray painting paradigm [59], and example-based editing for novices [38, 39]. Our decision to use L-systems rather than other models was guided by their simple formulation and deterministic nature.

Our research expands upon prior technical contributions by exploring unique affordances gained by thinking of L-systems as 2D ink (opacity-varying branches, hand-drawn stamps, 2D animation, and integration with familiar drawing controls like thickness and color), incorporating real-time visual feedback through live previews, enabling new forms of surprise through dynamic vector animations, making interactive L-systems accessible through an open web-based application, and most crucially by studying how continuous ink growth impacts artists' experience.

3 Design Considerations

Our design philosophy stems from the idea that an illustrator is situated in a feedback loop with their illustration tool [35, 52]. The design of L.ink is motivated by an attempt to balance two key properties of the feedback process: surprise and controllability. Formative user studies with artists and novices guided design choices towards achieving this goal. Formative study participants are assigned IDs beginning with "F" to distinguish from participants of the primary evaluation, beginning with "P." Two experienced artists (F2, F4) and two participants with no prior drawing experience (F1, F3) tested an early prototype version of L.ink. In the prototype, ink style customization was only possible by editing textual L-system rules, and manipulating parameters like branch angle and branch thickness via sliders. Each participant joined us for a 25 minute session in which they described their drawing background, explored the prototype in a 10 minute think-aloud session, and participated in a semi-structured interview. Interview questions asked for open-ended feedback with an emphasis on the participants' *experience* while using the tool. Participants were not directly asked about controllability or surprise, as we wanted to explore whether these themes would arise organically.

3.1 Surprising the Illustrator

The first property of interest is surprise, which we define as the degree to which the user (on average) is unable to predict how a tool will respond to their actions. Without surprise, the artist's choices are not influenced by their interactions with the tool, since they receive no new information from any given stroke. The design of our interactive growth algorithm aims to magnify the natural unpredictability of L-systems by triggering branching and turning of the stroke in real-time. We hypothesized that the living, moving quality of L.ink could involve artists more deeply in the process of reflection-in-action and reckoning with their medium to discover new creative ground [49]. While using the prototype, participants reacted with various forms of surprise, which we categorize as follows.

3.1.1 Initial Surprise. Some participants reacted with joyful surprise in response to seeing our real-time growth and animation effects for the first time. However, this initial reaction likely comes from the novelty of seeing something never before seen. Therefore, it is not necessarily unique to the L.ink drawing process, and should be treated separately from other types of surprise which continue throughout the drawing process.

3.1.2 Continuous Surprise. Besides the initial moment of surprise, participants also claimed to experience ongoing surprise as they interacted with the procedural growth effect mid-stroke. F4 said about the prototype:

> "*I think that's really fun when a tool surprises you and it's like an interaction between you and the tool... an open dialog where I do something and the tool responds in a certain way, and then that's something that you can play with.*"

F2 claimed that they couldn't predict exactly how the branches were going to emerge from their stroke at any given moment, especially when abruptly changing directions—they described this as "*exciting*" and "*organic*." The complexity of the real-time growth algorithm and speed-sensitivity led F1 to erroneously identify it as a stochastic process, claiming that the "random" variation between strokes made the tool more "*engaging*" and "*likeable*." These findings suggest that drawing with our L.ink prototype successfully evokes a kind of continuous surprise in the user, in which each instant of growth has an element of unpredictability. Furthermore, each L-system exhibits unique emergent complexity—modulated by stroke direction and speed—suggesting that continuous surprise would persist throughout extended use. While more detailed analysis was warranted to examine the impact on creative workflows, both novices and experienced artists considered this form of surprise to positively impact the drawing experience in this formative study, validating the prototype for continued development in this direction.

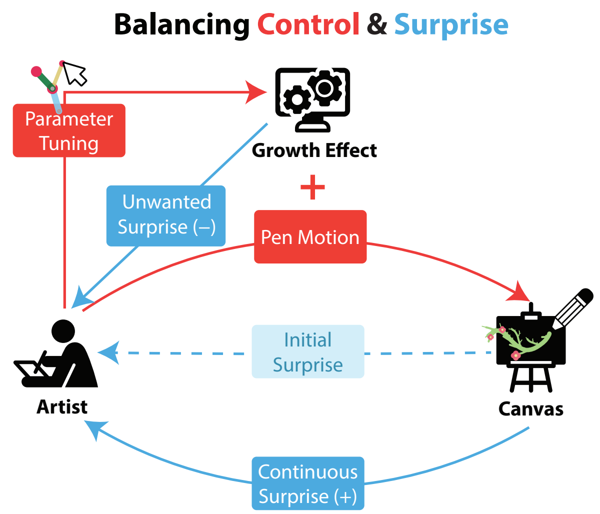

Figure 3: Blue arrows indicate surprise while red arrows indicate control. The primary feedback loop between the artist and canvas is controlled by *pen motion* and results in *continuous surprise* for the artist. *Parameter tuning* between strokes lets users alter the growth effect. We observed that *unwanted surprise* occurs when parameter tuning leads to unexpected results.

3.1.3 Unwanted Surprise. Not all forms of surprise were positive in this formative study—every participant reported at least one instance in which they changed an L.ink parameter to try to match an image in their mind, but when they drew with the L.ink the stroke's style was not what they wanted. This observation confirms that users desire a balance between surprise and control. Our strategy for achieving such a balance is described in the next section.

3.2 Tempering Surprise with Controllability

We relate controllability to prior literature on agency and autonomy [4], positioning L.ink as primarily studying experiential agency (focusing on artists' *experience* of control). Furthermore, we focus on both decisional and executional aspects of agency, occurring at a micro-interaction scale. This characterizes the setting of reflection-in-action, where artists rapidly and continually make choices and act in response to stimuli. Guided by psychological research on play, we hypothesize that effective controllability could encourage exploration by approaching the sweet spot of surprise, in which the user lacks complete understanding yet feels like they have the potential to acquire it [2]. In our formative study, participants favored the unpredictable mid-stroke dynamics of our real-time growth algorithm, but disliked unpredictability while editing L.ink parameters between strokes. Participants expressed frustration with alternating between editing and drawing in order to achieve the desired effect, and suggested adding a live visual preview to the editor to remedy this. F2 claimed that fine-tuning parameters in Blender with real-time feedback was one especially engaging part of their existing artistic workflows. F4 claimed that they like to work with interfaces that they can "*control like a tool, and fiddle and play with*

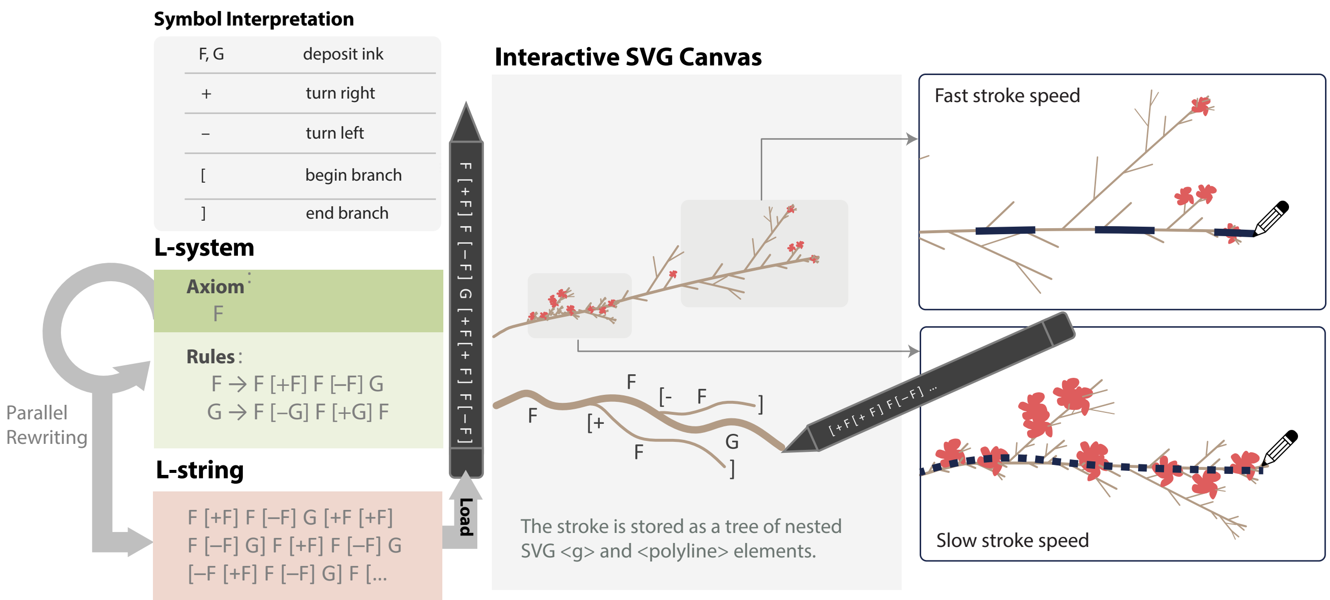

Figure 4: First, the L-string is generated by parallel rewriting. Second, the L-string is "loaded" into the pen like ink. Third, the user draws, triggering branching and turning effects as corresponding symbols are "fed out" onto the canvas. The user can vary the speed of the stroke to vary branch density.

like a toy." Altogether, these responses suggest that live feedback is an essential aspect of controllability, with the potential to minimize unwanted surprise and encourage exploratory play. Figure 3 illustrates the mechanics of controllability and surprise in the feedback loop model.

4 L.ink

Guided by our design considerations, L.ink introduces a continuous, interactive L-system growth technique. Furthermore, incorporating feedback from the formative study, L.ink is equipped with a direct-manipulation editor enabling artists to customize ink styles with immediate feedback.

4.1 Growing Ink

4.1.1 Interactive Growth. In L.ink, L-strings are pre-generated via standard (parametric) parallel rewriting [18, 32]. Interactivity is added during geometric interpretation of the L-string symbols.

As depicted in Figure 4, our method of enabling real-time growth can be thought of as "loading" the generated L-string into the pen like ink—as the user draws a stroke, symbols flow out of the pen sequentially, with some symbols depositing ink and others triggering real-time branching and turning of the stroke. All strokes with the same ink style use the same pre-generated string, and rewrite depth is automatically determined to prevent symbol depletion while drawing. In practice, our method of interactive growth is implemented by sampling the user's stroke into line segments at equal time intervals and associating each segment to a single "ink symbol." "Branch symbols" spawn new pen heads which follow the pen's motion transformed relative to their branch's coordinate system. This allows the user to draw curved, fluid branches, adding to stroke unpredictability. "Rotate" symbols transform the coordinate system of the branch in which they occur. Rotate symbols that occur on the base branch are ignored to prevent deviation of the stroke away from the user's pen. With fast enough stroke sampling, growth occurs smoothly and delivers continuous surprise to the artist.

L.ink strokes are represented and rendered through SVG group elements. Internally, each group represents the root of a scene graph consisting of all the branches and stamps associated with that stroke. SVG transform attributes structure the scene graph while animateTransform elements enable animations. Listing 1 shows how a scene graph node (representing a single branch) is structured.

```
<g class="node" transform=...>
    <polyline points=...></polyline>
    <animateTransform additive="sum" ...></
        animateTransform>
    <g class="stamp">...</g>
    <g class="children">
        ... //child nodes
    </g>
</g>
```

Listing 1: Example SVG for a single branch of an L.ink stroke

4.1.2 Ink Animation. To further enhance the fluidity of the growth effect, we apply an animated scaling effect to newly drawn branches, giving them the illusion of emerging seamlessly from their parent branch. These *ephemeral* animations last for less than a second and do not persist to the final work. Nevertheless, they enter the perception of the illustrator and thus have the potential to influence the

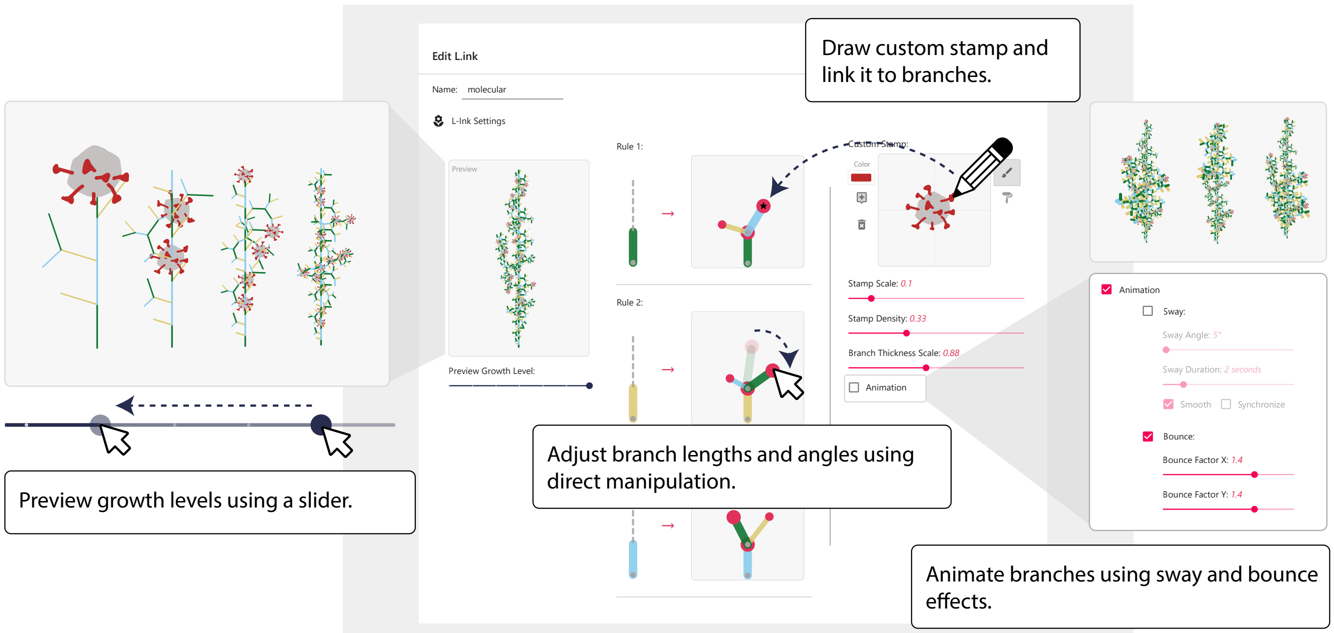

Figure 5: The L.ink editor contains (inner box, from left to right): An animated live preview that reflects parameter changes immediately. A rule-editor enabling direct manipulation of control points to change rule topology, branch angles, and branch lengths. A custom stamp drawing canvas and animation menu enabling expressive bounce and sway motions.

artists' reflection-in-action. L.ink also enables ongoing animations that continue after the stroke has been completed, making works created with L.ink *dynamic drawings* with *kinetic textures* [24, 25] upon SVG export. Ongoing animation uses 2 animation primitives: an animated scale (bounce) and an animated rotation (sway) which are applied to each branch individually, aided by our SVG scene-graph representation. When synchronized across a stroke, these primitives give rise to familiar swaying in the wind or pulsing kinetics. However, by de-synchronizing the motion of individual branches and linking the animation phase to the user's pen speed, novel organic motions like *writhing* and *undulating* become possible as well.

4.2 Ink Editor

To fulfill the design goal of effective controllability, we created an ink editor, depicted in Figure 5, that exposes rules and parameters of the L-system to the user through a direct manipulation interface. We build on prior work that represents rules by color-coded segments with draggable control points [21]. However, we augment this interface in multiple ways. First, drawing inspiration from our formative study findings and Victor's principle that "creators need an immediate connection to what they make" [56], we add a live visual preview which provides instant feedback when any parameter is changed. Second, we allow the user full freedom to modify the structure of the rules by adding and deleting branches and bends—making any parametric L-system rule reachable from any other rule via operations with real-time feedback. We hypothesize that being able to control ink parameters with immediate feedback will prevent unwanted surprise and encourage experimentation, letting the user actively explore variations of an otherwise unpredictable growth algorithm. Finally, we allow the user to add custom "stamp" symbols to the rules, enabling automatic procedural placement of hand-drawn flowers, fruits, leaves, or imaginative ornaments along the stroke. Stamps add yet another dimension of control, re-incorporating hand-drawn elements that preserve the artist's unique style. In total, the user has control over: number of branches, placement of branch origins, number of segments per branch, angles of segments, lengths of segments, branch length scales, branch thickness scales, and custom stamps. Furthermore, the user can add sway and bounce animations with tunable magnitude, duration, smoothing, and synchronization; editing these parameters also results in instantaneous feedback to the live preview, which is itself an animated SVG element.

5 Evaluation

We conducted a user-study to explore how L.ink impacts the creative workflows and experiences of digital artists. By exploring how artists interact and create with our tool, we validate the improved controllability of our direct manipulation editing interface, demonstrate that continuous surprise enhances engagement, and explore how L.ink drives reactive workflows to spark experimental ideas.

5.1 Participants

We recruited 12 participants who self-reported their digital illustration experience levels as novice (P05), intermediate (P01, P03, P04, P06, P07), advanced (P08, P09, P10, P11, P12), and professional (P02). Participants were recruited by physical postings and word-of-mouth around an art university. Although recruitment did not target specific genders, we recruited 11 female-identifying participants and 1 male-identifying participant. Each participant received a cash compensation of $25 for their participation.

5.2 Study Protocol

We conducted a task-based study with semi-structured interviews to investigate the potential impact of L.ink on artists. In particular, we were interested in studying three key questions. First, in what ways does the L.ink editor facilitate control? Second, what is the impact of continuous surprise on the felt experience of drawing? And third, how does L.ink impact artists' workflows?

To gain insight into these questions, we encouraged participants to think aloud during the entire session, and recorded interaction logs to capture patterns in user workflows while drawing. The study was conducted using a Wacom One Pen Tablet and 1920x1080 monitor.

5.2.1 ***Comparison Task (5 minutes)***. To evaluate the impact of continuous surprise, we asked participants to engage in an initial comparison task between varying levels of L.ink growth. Participants used 5 L.inks with the same underlying L-system rules but different branch lengths, from no growth (branch length 0) to large growth (branch length 1.2) in linear steps. Participants were asked to draw 3 strokes however they liked on an empty canvas with each of these 5 L.inks. The order of the 5 versions was randomized to reduce recency bias. After drawing 3 strokes with each L.ink, participants filled out a survey containing Likert-scale questions and a free-response question. Likert-scale questions assessed predictability of strokes, degree to which visual stimuli influenced stroke placement/direction, and engagement—using a subset of questions from the User Engagement Scale [36]. The free-response question asked for an open-ended impression of this version of the tool in the participants' own words.

5.2.2 ***Training (5-10 minutes)***. After this initial comparison task, participants were given a 5-minute training session explaining how to use L.ink. Participants were shown basic functionality like changing stroke size, opacity, and colors. Then, they were introduced to L.ink's growing ink styles with a basic explanation of iterative L-system growth, how to edit rules by direct manipulation, creating and adding stamps, and adding animation to strokes.

5.2.3 ***Structured Editing Task (5 minutes)***. Next, participants were shown preview images of 6 different L.inks, and they were asked to recreate these styles from 6 provided starting points (see Figure 6). Each of the 6 exercises evaluated a different skill in editing L.inks, as follows: (1) changing branch angles, (2) bending branches, (3) removing branch segments, (4) adding branch segments, (5) using multiple rules, (6) editing topology and geometry with multiple rules. Altogether, these 6 skills encompass the complete set of interactions required to achieve any L.ink from any starting point. The order of the exercises was not randomized, because later exercises built on the concepts learned in earlier ones. Each exercise was considered completed as soon as the participants' L.ink matched the target. Completion times were logged for each exercise.

5.2.4 ***Free Editing Task (5 minutes)***. After the structured editing task, participants were asked to explore the editing interface

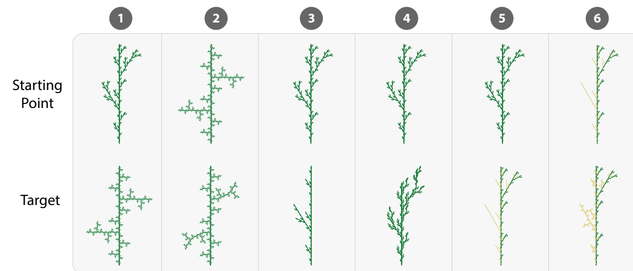

Figure 6: Participants were asked to create each target from the provided starting point during the structured editing task. Each exercise tests a different skill: (1) changing branch angles, (2) bending branches, (3) removing branch segments, (4) adding branch segments, (5) using multiple rules, and (6) editing topology and geometry with multiple rules.

freely to generate as many diverse ink styles as they could for 5 minutes. Participants were free to create new L.inks, edit the preset L.inks, or edit L.inks from prior tasks. They were also able to test out the ink styles they created by drawing on the canvas during this task.

5.2.5 ***Free Draw (25 minutes)***. Finally, participants were given 25 minutes to create an illustration using L.ink. They were able to use and edit any prior ink style they had created, or create new ink styles during this session. Participants were also free to draw strokes with no ink style applied, as long as they explored how to use L.inks creatively. At the end of the session, final SVG outputs were saved. In some cases, participants opted to create multiple works, resulting in multiple SVG files. In these cases, the researchers chose to present the work that they felt best exemplified the artists' use of L.ink.

5.2.6 ***Semi-Structured Interview (10 minutes)***. At the end of the session, we conducted a semi-structured interview with artists to better understand their decisions, thought processes, and experience while using L.ink.

6 Results

In this section, we extract findings from the aforementioned surveys, tasks, and interviews to examine L.ink's impact through the lenses of controllability and surprise. Furthermore, we report findings demonstrating how L.ink transforms artists' workflows and actively drives them to generate diverse outputs.

6.1 Continuously Surprising Ink Growth Increases Artist Engagement

We report qualitative and quantitative results for the impact of ink growth on engagement. Table 1 shows the median responses for all Likert scale questions across 5 degrees of ink growth, as measured by branch length. A Friedman test was conducted to evaluate differences in Likert responses across these 5 conditions. This non-parametric test is appropriate for ordinal data with repeated measures. The results indicated at least one statistically significant ($p < .05$) difference in conditions for the statements, "I

Likert Statement	*branch_length* = 0.0	0.3	0.6	0.9	1.2	$\chi^2(4)$	p
I lost myself while drawing.	2.0	2.5	3.0	3.0	3.0	9.70	.046*
I blocked out things around me while drawing.	2.0	2.0	2.5	3.0	3.0	3.47	.483
I felt involved in this experience.	3.5	4.0	4.0	4.0	5.0	8.38	.079
This experience was fun.	3.5	4.0	4.0	5.0	5.0	12.02	.017*
Drawing with this tool appealed to my visual senses.	3.0	3.5	4.5	4.0	5.0	17.69	.001*
What I saw appearing onscreen influenced the placement or direction of my strokes.	3.5	4.0	4.0	4.0	4.5	10.38	.035*

Table 1: Median Likert ratings by degree of ink growth (branch length). Values for χ^2 and p were calculated with a Friedman test. Asterisks indicate at least one statistically significant ($p < .05$) difference between conditions.

lost myself while drawing," "this experience was fun," and "drawing with this tool appealed to my visual senses." Median ratings for these statements generally increased with increasing branch length, suggesting that ink growth positively impacted these aspects of engagement. There was also at least one statistically significant difference between conditions for the statement, "what I saw appearing onscreen influenced the placement or direction of my strokes," suggesting that ink growth could impact artists' on-the-fly decision-making. We omit results for the statement, "I was able to predict the visual result of my actions while drawing" because poor phrasing cued participants to answer based on the predictability of the condition they would receive next rather than the predictability of the tool. This was corroborated by free-responses; for example, a participant who received the no-growth (branch length 0) condition after a growth condition rated low predictability (rating of 1) and wrote, "*Surprised by the lack of branches.*" Another participant receiving multiple growth conditions in a row rated high predictability (rating of 5), writing, "*It feels the same as the previous drawing experiences.*" For complete frequency responses for all Likert questions, see Appendix A.

We turn to think-aloud and interview responses to better understand L.ink's impact on engagement. P09 claimed that ephemeral growth animations captured their attention more than their drawing itself: "*I was watching the animation of it growing out more than what I was drawing, really. I think that was really satisfying.*" Watching their stroke's growth also had a "*therapeutic*" effect for P12, who felt compelled to draw around the page with no particular goal in mind. They compared watching growing L.ink strokes to observing fish swimming in a tank, echoing P05's comment that their stroke had *"a mind of its own."* P02 related L.ink to forms of creative play that emphasize the experience over the end product: "*It feels more like something that you are experiencing . . . when you were at a children's museum as a kid, the drawings that you made were more about doing it than whatever you could create at the end, like with an Etch-A-Sketch.*" Altogether, these results point towards the notion that the continuous unpredictability of growth animations captured and held participants' attention while drawing, contributing to overall engagement.

Editing Exercise	Completion %	Avg. Time (s)
Changing Branch Angles	100	20.2
Multiple Rules	92.3	12.5
Multiple Rules 2	84.6	29
Removing Branches	84.6	7.6
Adding Branches	76.9	19.7
Bending Branches	38.5	31

Table 2: Completion percentage and average time to finish for structured editing exercises.

6.2 Direct Manipulation Improves L.ink Controllability

Based on feedback from our formative study, we provided a direct manipulation rule editor and live visual preview to increase users' control over L.ink customization. In the structured editing task, we find that participants were able to customize L.ink styles efficiently and effectively using the newly added interface. Due to time constraints, we stopped participants after 1 minute had elapsed, so we consider editing times of longer than 1 minute to indicate failure to achieve the target style. As shown in Table 2, most participants were able to achieve the target ink styles within this 1 minute time limit for 5 out of the 6 exercises. Participants consistently took longer (31 seconds on average) and struggled (38.5% completion rate) with bending branches, which they found unintuitive at first. This makes sense, as creating L.inks with curved branches does not involve creating curved rules (rather, a single bend gets repeatedly duplicated to become a curve), breaking the direct one-to-one relationship between the preview and the rules—future work could explore more intuitive methods of branch curving. Besides this minor point, the editor's controllability shows considerable improvement over the textual editor of our prototype, resolving the unwanted surprise and lack of control felt by participants who tried customizing rules in the formative study.

When given the chance to interact with the editor in an open-ended way, participants further demonstrated that they were able to leverage this control for creative purposes. Participants showed a preference for remixing existing presets and ink styles from prior

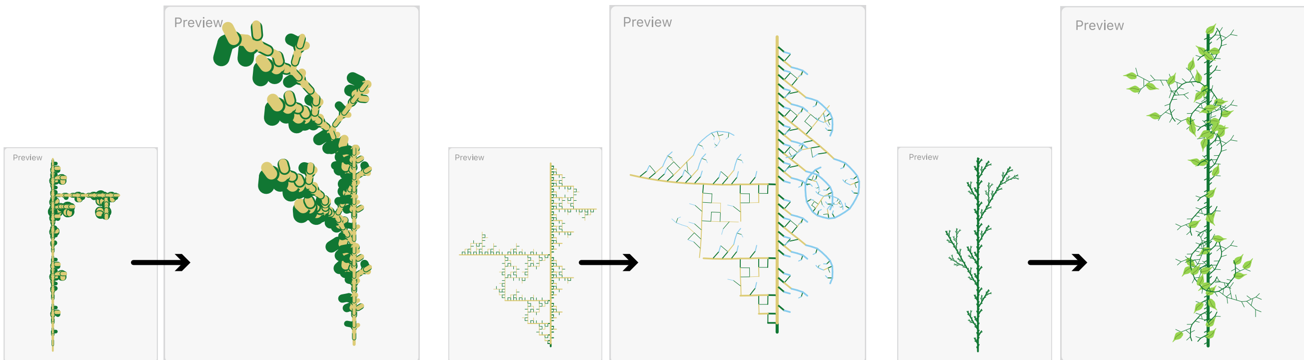

Figure 7: Previews of three L.ink styles created by participants using the editor during the free-editing and free-draw tasks. Smaller images to the left of the arrows show preset styles that participants used as starting points. Participants were able to achieve expressive styles that diverged from the presets.

exercise tasks rather than creating L.inks from scratch. Using presets as starting points, they tuned rules and parameters to explore a wide variety of visual styles which often diverged greatly from the original preset. Three examples of L.ink styles created by participants are shown in Figure 7. As illustrated by the leaves in the rightmost L.ink of Figure 7, some participants also opted to add hand-drawn stamps during this phase. Participants’ fluent use of the various editing interactions to generate original ink styles illustrates that our editor facilitates not only goal-oriented control, but also open-ended customization.

Feedback from think-aloud transcripts and interviews reveals more detailed attitudes towards L.ink’s controllability. Multiple participants (P01, P02, P07, P11) explicitly mentioned that stamps were a favorite feature of the editor, with P07 claiming, “*it was like the ultimate customization out of all of it.*” For P02, the live preview was a “*really crucial*” part of editing, that even helped them to learn the mechanics of L-system growth. P11 felt that the preview made editing into its own engaging interaction (“*I would spend tons of time just to explore this,*”). They were specifically engaged by the preview’s real-time responses, saying, “*compared to other drawing tools, this is definitely an impressive feature.*” While this feedback highlights strengths which boosted the experience of control, some participants also expressed frustration with certain aspects of the editor. P01 and P02 felt that the editor presented too many tunable variables, making it “*hard to know where to start*” and “*easy to get overwhelmed.*” Additionally, P12 expressed frustration when their strokes did not match their expectations based on the preview. They suggested shaping the preview more like a user-drawn stroke to remedy this. As a note, later quotes that mention uncontrollability or lack of control reference the process of drawing a stroke, not the process of authoring an L.ink style. Using these terms for the stroke-drawing process is expected and distinct from the controllability of our editing interface.

Overall, we find that the additions after our formative study—the direct manipulation rule editor, live previews, and hand-drawn stamps—increased the controllability of L.ink for both structured and open-ended customization of ink styles. These controllability strategies helped achieve a balance with L.ink’s surprising ink growth.

6.3 L.ink Encourages Experimental Flow Towards Diverse Outputs

In the free draw task, participants brought together controllability and surprise, freely using all the features of L.ink to author a final illustration. Our analysis of this culminating task reveals that participants use L.ink to generate works which are diverse in both style and subject (shown in Figure 8) and exhibit highly creative uses of the tool’s generative capabilities. We further find that the diversity of outcomes is brought about by L.ink’s stimulation of experimental flow in participant’s illustration workflows.

In their final works, participants used L.inks to draw plants as expected, but they also used them to represent a diverse range of objects including lightning bolts, oozing slime, ornamental bridges, feathered wings, a lion’s mane, coral, fish fins, clouds, internal organs, and hair. Some participants also used L.inks to generate various *textures* like rocks, flowing water, pufferfish spikes, bricks, shower tiles, and graffiti. The rich variety of visual motifs confirms that users with control over L.ink authoring create strokes that have expressive power beyond the common uses of L-systems. More importantly, the diversity we observed warranted further investigation to identify how it arose from user workflows.

When asked about their workflow, participants consistently said that they felt like they lacked complete control while drawing. Some participants (P03, P06, P07, P09, P11) explicitly viewed this lack of control as a positive. As P03 said, ‘‘*I was less in control, which fascinated me. It’s not a bad thing.*” These participants seemed to embrace the unpredictable nature of L.ink, a mindset that P06 described as “*lean[ing] into the randomness of the stroke*” and “*not try[ing] to force the brush to work in a certain box.*” P03 further claimed that L.ink strokes actually led their work in a particular direction, stating, “*I was able to follow the flow of where the software was taking me, and go from there.*” These participants exhibited

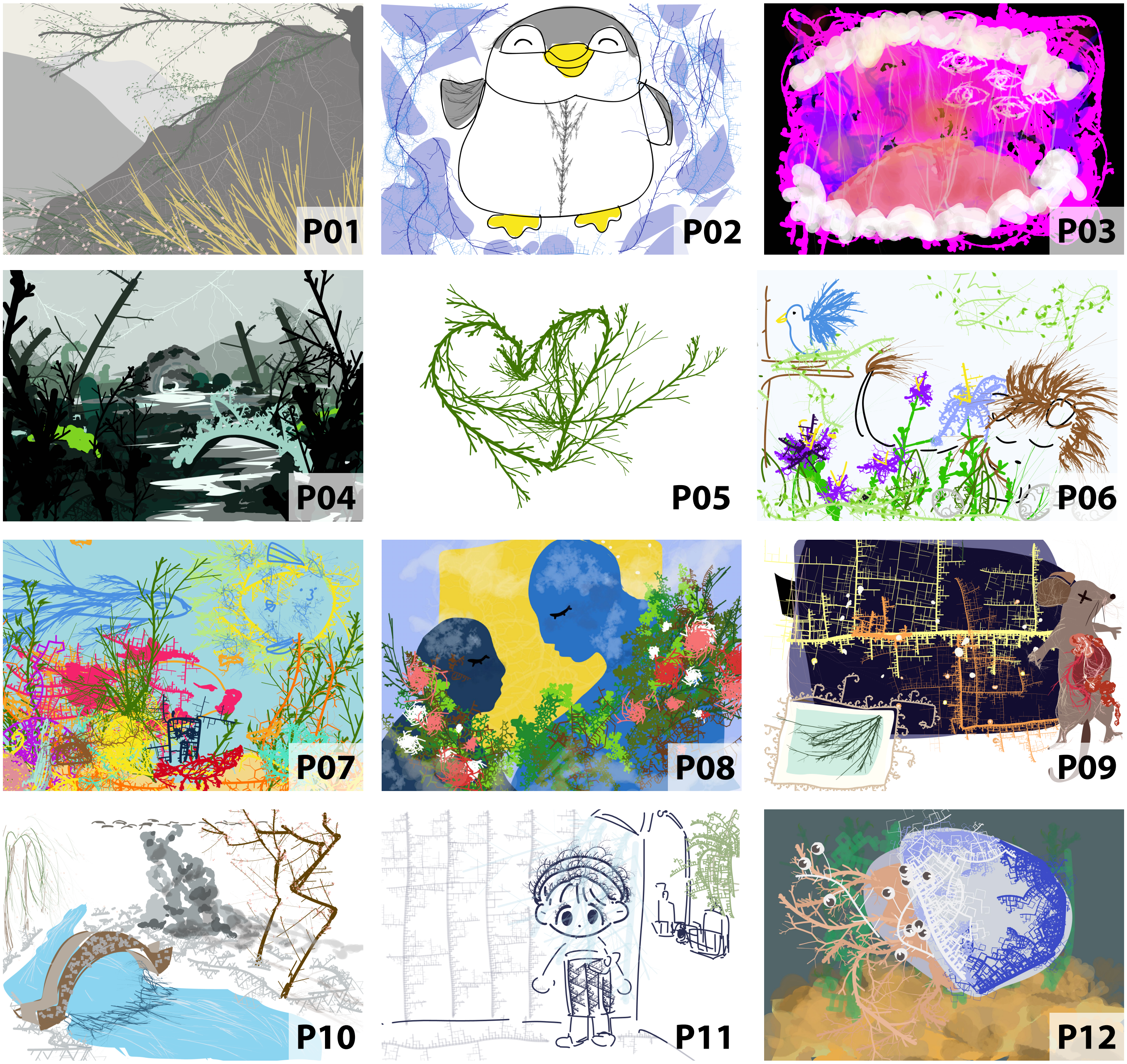

Figure 8: Final participant illustrations created with L.ink. L.inks were used to represent objects like lightning bolts, oozing slime, ornamental bridges, feathered wings, a lion's mane, coral, fish fins, clouds, internal organs, and hair. Other participants used L.inks to generate textures like rocks, flowing water, pufferfish spikes, bricks, shower tiles, and graffiti spray paint. On average, final works contain 160 polylines per user-drawn stroke. Some works also contain animated strokes.

the tendency to smoothly incorporate unpredictability into their workflows rather than fight against it.

The participants that adopted this mindset further explained what "following the flow of the software" looked like in practice. P06 described how their creative decisions were dependent on the previous moment of growth: "*A lot of it was just seeing where [the growth] would go, then basing my next move off of where the last move went.*" P10 expressed the same: "*As I'm drawing a branch with the growing effect, sometimes I draw one line, pause, and then draw in another direction . . . I feel like I'm considering which direction it* *grows into to see which direction I'm going to go to next.*" For these participants, each artistic choice was influenced by the system in a visual feedback loop. According to P10, all of this happened naturally and unconsciously: "*It wasn't too much of a thinking, intentional choice, but at that time I just felt which way to go.*" These participants continuously negotiated with the system.

Participants felt that this act of continuous negotiation gave them freedom to explore new creative directions, with P03 stating, "*The less control I had over the software itself, the more creative liberty I had to lift myself . . . into a more experimental zone.*" They explained that the uncontrolled aspect of L.ink strokes functioned as an "*external force*" that freed them from their own thought patterns. The result was that these participants repeatedly re-invented their ideas during the free draw session and took their drawings in new and surprising directions. For example, P06 began by drawing a flower with an animated sway effect, then said, "*as I'm drawing, I'm getting ideas . . . I could have made this an animal . . . I'm gonna try to add an animal maybe*," then proceeded to add a lion with an L.ink mane to the scene. Later, after drawing an oval shaped L.ink stroke that grew into an ornamental pattern, they declared, "*He's going to be protecting eggs.*" The unexpected final subject of the illustration, a lion protecting eggs, emerged from P06's willingness to follow the unexpected growth of L.inks into new directions. P09's work began with a rectilinear pattern reminiscent of a city map. However, they changed direction entirely after receiving inspiration from the green strokes they drew across an ornamental frame: "*That one looks like a vascular system.*" From this point on, the participant focused on creating the graphic insides of a dead rat, a complete departure from their prior subject but resulting in a compelling art piece evoking a unique aesthetic.

The finding that unpredictable tools can lead artists down new creative avenues suggests generalizable insights for CST design. These insights, and recommendations for when they do and do not apply, are further discussed in the following section.

7 Discussion

While some participants leaned into their incomplete control and followed unpredictability in new creative directions, others felt frustrated by it. This prompted the question: what factors influence an artist's reaction to a lack of control? In exploring these factors, we extract recommendations for when creativity support tools should and should not incorporate unpredictability. In cases where unpredictability is suitable, we further discuss its potential to bring organic variety to digital tools, and conclude by suggesting intentional workflow disruption as a way to support divergent thinking in the ideation phase.

7.1 Cases for Control

We found that participants who already had a clear mental image of what they wanted to create tended to react negatively to their incomplete control over the system. P05 explained, "*I had a vision . . . so I wanted to actually render it . . . but it was not rendering the image that I had in my head,*" showing that attempting to directly put a preconceived idea on the canvas is difficult when working with unpredictability. P11 said, "*I do like the uncontrollable part if I'm creating artworks freely, not thinking of a specific item that I want to create. But if I'm trying to create a specific pattern or object, I would still tend to use normal [tools].*" P12 agreed, adding the minor caveat that with enough practice, they might be able to render a preconceived visual look. All in all, this leads us to recommend that creativity support tools that focus on implementation of preconceived ideas use unpredictability sparingly. This finding also implies that uncontrollable tools might be best suited for creating abstract works which would be difficult to visualize regardless, and poorly suited for highly realistic subjects or styles.

Additionally, we believe that expert artists may find unpredictable workflows less desirable than other artists. This theory is supported by the experience of P02, who struggled to break from their habitual workflow while using L.ink: "*I don't think [about] things that are going to be coming out of my stroke.*" In one instance, P02 tried drawing with an L.ink reminiscent of hair, but deleted their strokes, stating, "*For the hair, it's more common for me to only do a few strokes for effect, so the hair brush is too detailed.*" In this scenario, P02 compared L.ink against their existing workflow to evaluate fit. It seemed clear that this expert artist sought a more seamless integration into their existing practice. While P02 was the only expert artist in our study, this idea is also supported by the theory that artistic mastery is composed of layers of habits [15]. This being the case, disrupting the workflow of an expert artist may be functionally equivalent to removing their mastery. If creativity support tools aim to facilitate skillful use by experts, unpredictability and incomplete control may not be desirable features to include.

This discussion of artists' willingness to relinquish control evokes themes of power as discussed by J. Li et al. [30] In L.ink and other generative art tools, the tool itself exerts a kind of "will" which does not necessarily align with the artists' own will. Artists working with such mediums can surrender to the "out-of-control nature of nature" [34]—conceding power to the system—or attempt to exert power over the system to produce their desired output—a process likened to taming a wild horse by a user of the No-input Mixing Desk [35]. In either case, the artist's capabilities are constrained by *fluid negotiations* in addition to fixed affordances, imposing a kind of soft boundary on the CST's normative ground [30].

7.2 Bringing Organic Variety to Digital Tools

In other cases, unpredictability presents the potential for distinct benefits. Participants consistently felt that L.ink worked best for drawing freely, without a specific goal in mind. Specific scenarios that P03 brought up included "*idea inspiration*," "*storyboarding*," and "*sketching to get your mind going for the day.*" In these and related scenarios, we suggest that unpredictable tools offer a unique edge over traditional digital tools.

The theme of "organic-ness" was brought up by many participants (P01, P02, P04, P07, P12) using L.ink. While this word sometimes simply implies a relation to living things (which L.ink clearly has), participants also used it in a different way, suggesting one way in which L.ink was distinct from other digital illustration tools. P04 said, "*when you're using [L.ink], drawings end up a little imperfect, like not perfectly straight or anything. And I guess that makes a more organic feeling.*" The interpretation of organic-ness as imperfection or a break from rigidity suggests a potential method of disrupting digital uniformity, a limitation in traditional tools that P06 identified: "*A lot of digital drawing is very calculated.*" P09 also expounded on this limitation, saying, "*with drawing digitally you kind of always know what you're going to get, and I think that's why it's harder to make an interesting image digitally.*" They then suggested that L.ink remedied this, claiming that layering multiple L.ink strokes allowed them to create an image which was "interesting" in the way that other digital images were not.

The way that L.ink generates organic variety is not random—rather, it relies on the emergent visual interest of the underlying L-system. The L-system is an inherently computational object, but nevertheless generates deep visual complexity, complete with subtle "imperfections." By harnessing its inherent structure, flaws, and surprise with some degree of control, artists gain the ability to bring life back into their digitally created images. Furthermore, L-systems represent just one procedural "engine" for emergent complexity. This work opens avenues for future work exploring how other procedural models might be harnessed to impart digital creativity tools with touches of organic interest.

7.3 Disrupting Ingrained Workflows

Our findings confirm that surprise can have a positive influence on creative workflows—we found that for some participants, the surprising nature of L.ink encouraged experimentation by disrupting habitual patterns. It seems that this effect was caused by ink growth as an external force constantly introducing new stimuli—in cases where artists might normally have followed a set of ingrained steps, the tools' surprising growth forced them to dynamically adapt their plan. The continuous aspect of surprise amplified this effect even further by *constantly* introducing differential surprises to drive artists down new creative branches. In this way, unpredictability made it impossible for artists to stick to a preconceived plan, instead necessitating repeated re-evaluation and innovation.

The finding that continuous surprise enhances experimentation complicates the notion that creativity support tools should integrate seamlessly into existing artistic workflows [19, 22]. Specifically, our result suggests that intentionally disrupting familiar workflows can more effectively support ideation and increase divergent thinking. Insights from psychology support this finding, showing that reliance on habits may negatively impact creative ideation [10, 20], while imposing constraints may have a positive impact [55]. Through this lens, traditional creative tools with seamless workflow integration may actually cause over-reliance on habitual processes, limiting artists' ability to discover fresh ideas or aesthetics. Creativity support tools that intentionally disrupt existing workflows to promote ideation present an opposing approach that warrants further research. L.ink demonstrates that elements of surprise, and specifically continuous surprise, are one way to implement intentional workflow disruption. As of Frich et al's survey, the ideation phase is the phase most commonly supported by creativity support tools, with 45% of works claiming to support this phase [13]. If supporting creative ideation is the goal, then perhaps seamless integration is not always the best design criterion to encourage experimentation. Instead, our results support the ongoing exploration of CSTs that place users in feedback loops, continually introducing moments of surprise to spark inspiration [35].

8 Limitations and Future Work

L.ink suggests promising directions for future work exploring how digital artists engage in conversation with their tools. While we do not expect any of our analysis to be dependent on gender, future work could verify this with a more gender-diverse participant pool. We foresee broad applicability of the themes of incomplete control and conversing with tools, especially given the increasing prevalence of generative AI. Future work could also benefit from exploring how surprise relates to other key illustration concepts or other forms of digital art, as the strategies for achieving an appropriate balance likely depend on the medium in question. While L.ink largely focuses on micro-scale surprise (continuous ink growth) and macro-scale control (ink editing between strokes), another fruitful area could be to explore alternative paradigms. For example, while drawing is a naturally continuous process, perhaps systems supporting discrete processes like collage could study macro-scale surprise.

We also see potential to explore the rich properties of L-systems beyond controllable surprise. Future work could draw from the programming languages literature to explore interaction methods that engage directly with the recursive, programmatic structure of L-systems.

9 Conclusion

In this paper, we present L.ink, a digital illustration tool empowering artists to draw with controllably-surprising, growing ink. We demonstrate a real-time interactive growth algorithm with fluid branching, a natural stamp placement paradigm, and animations that arise seamlessly from our hierarchical SVG stroke format. Early formative studies revealed that direct-manipulation could offset unwanted surprise, guiding our creation of an L.ink editor with live preview. Our evaluation demonstrated that L.ink strikes an effective balance between control and surprise and drives artistic experimentation towards diverse subjects and styles. Finally, we presented recommendations contextualizing when and why unpredictability should be incorporated into creativity support tools, including its potential to bring organic variety to digital art forms and disrupt ingrained workflows. We believe that L.ink engages with important questions: How can artistic tools enhance artists' embodied experience in addition to their output? How might other imperfect, surprising, or uncontrollable tools affect the creative process? Our work adds to the ongoing conversation exploring the complexity of what it means to be creative [19] and to support creativity [48].

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A Likert Response Frequencies

We report complete Likert rating frequencies from our comparison task in Figure 9.

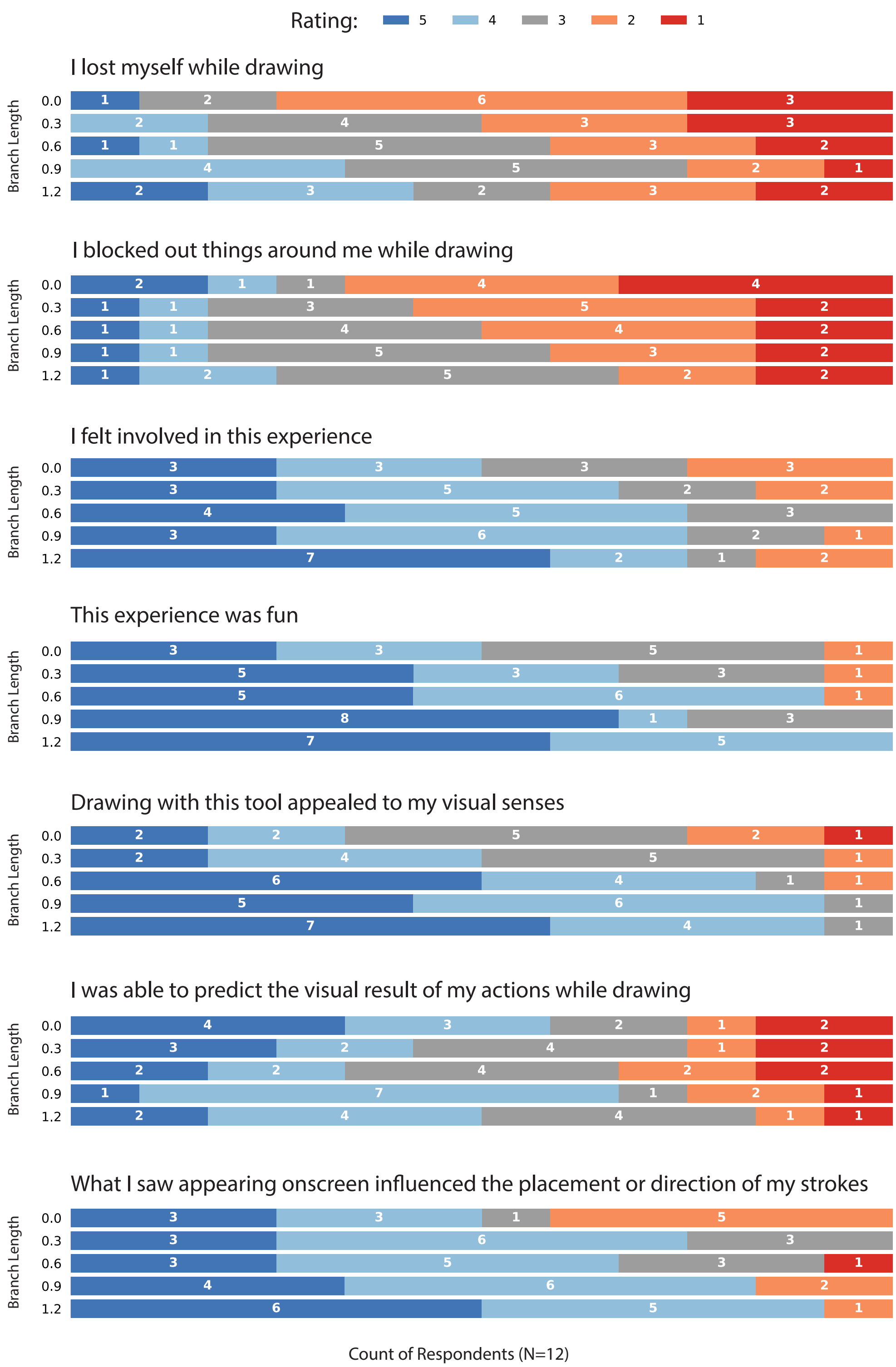

Figure 9: Likert rating frequencies for all seven comparison task statements by degree of ink growth (branch length).