Author manuscript, published in IEEE Transactions on Visualization and Computer Graphics, 25(1), pp. 277-287, 2019.
DOI: 10.1109/TVCG.2018.2864887

InkPlanner: Supporting Prewriting via Intelligent Visual Diagramming

Zhicong Lu, Mingming Fan, Yun Wang, Jian Zhao, Michelle Annett, and Daniel Wigdor

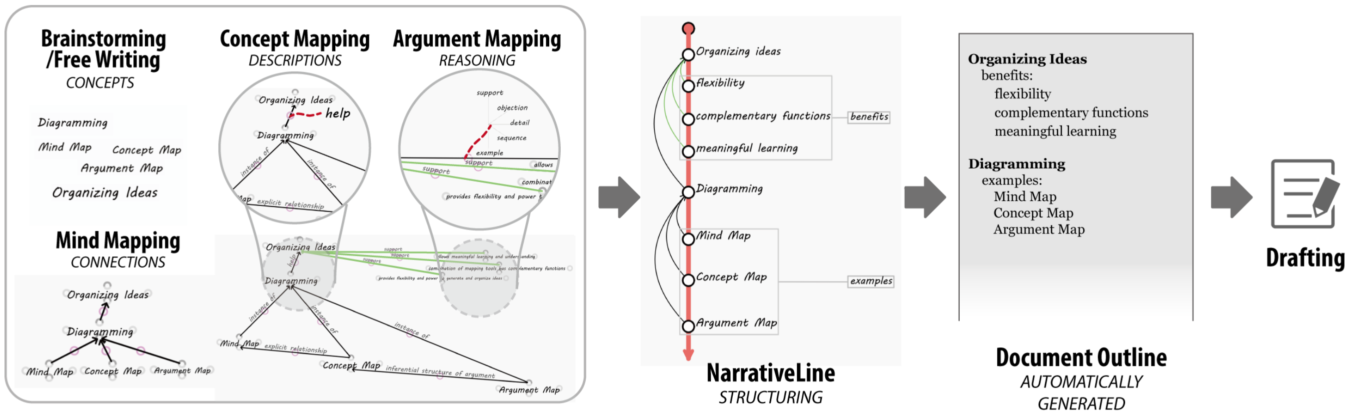


Fig. 1. The workflow supported by InkPlanner: (a) five prewriting strategies can be used in an interleaved manner during the prewriting of a document, (b) the NarrativeLine can be used to organize diagrams of ideas into a logical story, and later, (c) an outline can be automatically generated for use during drafting.

Abstract—Prewriting is the process of generating and organizing ideas before drafting a document. Although often overlooked by novice writers and writing tool developers, prewriting is a critical process that improves the quality of a final document. To better understand current prewriting practices, we first conducted interviews with writing learners and experts. Based on the learners' needs and experts' recommendations, we then designed and developed InkPlanner, a novel pen and touch visualization tool that allows writers to utilize visual diagramming for ideation during prewriting. InkPlanner further allows writers to sort their ideas into a logical and sequential narrative by using a novel widget— NarrativeLine. Using a NarrativeLine, InkPlanner can automatically generate a document outline to guide later drafting exercises. Inkplanner is powered by machine-generated semantic and structural suggestions that are curated from various texts. To qualitatively review the tool and understand how writers use InkPlanner for prewriting, two writing experts were interviewed and a user study was conducted with university students. The results demonstrated that InkPlanner encouraged writers to generate more diverse ideas and also enabled them to think more strategically about how to organize their ideas for later drafting.

Index Terms— Writing; prewriting; diagraming; content and structure recommendation; pen and touch interfaces.

1 Introduction

Writing is a highly complex activity that involves many integrated skills, such as organizing available resources and evidence and generating ideas and arguments. *Prewriting*, i.e., the process of planning and organization of ideas before composing a first draft, has been demonstrated to be effective in improving the quality of a final document by decreasing memory overloading during planning [20] and drafting [3, 27]. Because writing is viewed as a set of complicated processes and skills that are difficult to master [20], many educational researchers have proposed prewriting as an important stage of the writing process and have advocated that educators should teach prewriting strategies to help students learn to write [3].

Several different prewriting strategies have been proposed by educators to support brainstorming, idea generation, and knowledge organization during the planning of one's writing. The educational literature suggests that combining different visual diagramming strategies during a prewriting process (e.g., mind mapping and concept mapping) can enable writers to have more flexibility and power [13]. However, current prewriting tools do not support a variety of prewriting strategies or enable for streamlined prewriting workflows. Consequently, writers must switch between different views, or even different applications, to combine strategies. Further, the outcomes of prewriting activities (e.g., diagrams) can be complicated and nonlinear. As a result, a writer must further filter and structure their ideas, which are often diverse and seemingly unrelated, into a sequential and logical form to create a coherent narrative.

To address the above issues, we first conducted interviews with writing experts and students to understand current prewriting practices. These interviews revealed that prewriting tools do not support a richer set of prewriting strategies, facilitate the sorting of ideas into logical sequences to guide drafting, or enable free-form pen and touch interactions. Inspired by these findings, we then developed InkPlanner, a prewriting tool that supports five major prewriting strategies via visual diagramming (i.e., *brainstorming*, *freewriting*, *mind mapping*, *concept mapping*, and *argument mapping*) within a fluid integrated workflow (Figure 1). InkPlanner was built for a mobile tablet and uses intuitive pen and touch interaction to mimic traditional pen and paper writing experiences, while also leveraging the advantages of digital devices (e.g., the ability to search and reuse diagrams), and the fluid, bimanual gesture support of tablets [22]. We further designed a novel visualization widget, *NarrativeLine*, to assist

- *Z. Lu, M. Fan, and D. Wigdor are with University of Toronto. Emails: {luzhc, mfan, daniel}@dgp.toronto.edu.*
- *Y. Wang is with Hong Kong University of Science and Technology. Email: ywangch@connect.ust.hk.*
- *J. Zhao is with FX Palo Alto Laboratory. Email: zhao@fxpal.com.*
- *M. Annett is with MishMashMakers. Email: mishmashmakers@gmail.com.*

*Manuscript received xx xxx. 201x; accepted xx xxx. 201x. Date of Publication xx xxx. 201x; date of current version xx xxx. 201x. For information on obtaining reprints of this article, please send e-mail to: reprints@ieee.org.
Digital Object Identifier: xx.xxxx/TVCG.201x.xxxxxxx/.*

writers in transforming their two-dimensional diagrams into linear, logical narratives. To inspire writers and help them overcome writer's block, we also developed a machine-learning recommendation algorithm that provides content- and structure-based suggestions to writers to further enhance their workflows while prewriting.

To evaluate InkPlanner, we conducted expert interviews with two expert writers who used InkPlanner and provided their feedback. To understand how the tool was used by students for prewriting and drafting, we also conducted a user study, in which students used InkPlanner to plan and compose academic essays. The results from both efforts demonstrated that InkPlanner could and did encourage students to generate more ideas and organize those ideas in better forms. Based on the feedback from the expert interviews and user study, we also highlight potential directions for future research.

2 Background and Related Work

2.1 Existing Prewriting Strategies and Usage

Prewriting, i.e., the process of planning and organizing ideas before drafting using diagramming, clustering, or outlining, has been a popular pedagogical approach to improving writing skills for more than five decades [50]. While a review of prewriting strategies can be found in Baroudy [4], we differentiate strategies that aim to overcome writer's block (i.e., unstructured strategies), from those focusing primarily on organizing existing ideas (i.e., diagram-based strategies).

Prewriting strategies that are unstructured take many forms, for example, talking [1], browsing [4], incubating [35], questioning [4], journaling [15], cubing (i.e., looking at an idea from six different points of view, including description, comparison, analysis, association, application, and persuasion [29]), and invisible writing (i.e., freewriting by typing on a computer with a black screen [34]). In this work, we concentrate on two common unstructured prewriting strategies: *brainstorming* and *freewriting*. *Brainstorming*, also known as *listing*, involves writing down as many ideas as one can without grouping them or evaluating them for quality [47]. *Freewriting* encourages writers to write phrases or sentences for a prescribed number of minutes, non-stop. It can be used to empty a writer's mind of every day distractions to explore ideas about a topic [29].

Diagram-based prewriting strategies, also known as *clustering techniques*, which allow a writer to construct a visual network of ideas, have been shown to be effective in "stimulating the unconscious design processes that are the source of creativity" [49]. In this work, we focus on three diagram-based clustering techniques: *mind mapping*, *concept mapping*, and *argument mapping*. A *mind map* helps writers make associations between ideas, concepts, or images [10], that can aid in memory retention [17] and idea organization [48] while prewriting. A *concept map* is a relational device with a hierarchy [40], that has also been shown to improve writing ability "in terms of the quantity and quality of generating, organizing, and associating ideas" [45]. Different from a mind map, a concept map is less pictorial and more structured [13]. Finally, an *argument map*, which is more granular, clarifies the inferential structure of arguments and logical connections, and helps a writer evaluate premises and increases their immediate recall of arguments [14].

Previous research has suggested that combining these prewriting strategies in an integrated environment would provide more flexibility and power to writers [13, 16]; however, no such system has been developed. To our knowledge, InkPlanner, is the first attempt to integrate multiple prewriting strategies in one integrated environment. InkPlanner integrates two main unstructured strategies, i.e., freewriting and brainstorming, and several clustering techniques, i.e., mind mapping, concept mapping, and argument mapping. Although not directly supported by InkPlanner, other strategies such as incubating and cubing can be used implicitly with InkPlanner for idea generation and organization due to the free-form, paper-like affordances within InkPlanner.

2.2 Tools and Techniques to Support Writing

Several systems have been proposed to support different phases of the writing process, including ideation, prewriting, drafting, rewriting, and editing. For example, Liu et al. explored how to use questions to inspire writers to generate better ideas [31, 32], whereas Mining Memories helped high school students begin writing by mining their existing content on social media [51]. These systems can assist writers during prewriting, but focus on idea generation and only support one prewriting strategy. In contrast, InkPlanner supports several prewriting strategies that are more visual and graphical in nature, provides flexibility for using different strategies simultaneously, and focuses on idea generation and content organization.

Other systems have proposed using feedback to improve writing, such as Uto et al.'s system that used Bayesian Networks to support argument elaboration while writing [55]. Glosser provided writing feedback and suggestions on structure, coherence, and topics using text mining [56], whereas O'Rourke et al. visualized the similarity of paragraphs [41] and topic flow [42] to support academic writing. These systems provide writing feedback by showing suggestions or information explicitly during drafting or editing phases. Their user interfaces supported text editing or spreadsheet manipulation in traditional desktop or laptop settings. In contrast, InkPlanner empowers writers during prewriting by supporting pen-and-touch interactions on mobile tablets and providing semantic and structural suggestions generated by machine learning techniques.

2.3 Digitally-Based Visual Diagramming Tools

Several commercial diagramming tools have been developed and widely used for education, knowledge management, business management and collaborative work [10], including iMindMap [60], FreeMind [38], Cmap [19], and Rationale [46]. They all, however, require users to create diagrams with prearranged layouts rather than provide them with free-form user interfaces. Most also focus exclusively on the development of tree structures, so writers can only build diagrams that resemble networks. Although iMindMap and Cmap have mobile versions, their interfaces require that a keyboard and a mouse be used for diagramming. Furthermore, unlike InkPlanner, these diagramming tools were not specifically designed for prewriting and do not harness the natural affordances that pen and touch input enable.

Another set of diagramming tools that were built with pen and touch interactions allow users to focus on tasks without having to worry about precision [25, 54]. In addition to diagramming, many novel applications of pen and touch gestures have been proposed, including handwriting [5], note-taking [23, 24], sketching [18, 26, 44], sense-making [8, 10], problem solving [59], and visualization [21, 28]. Many tools have been developed to aid pen-based diagram creation. SetPad enabled users to explore discrete math problems by portraying set expressions using pen-based input [12]. SketchSet supported users in creating and editing Euler diagrams via sketch-based interactions or mouse editing [53, 58]. SketchViz enabled dynamic domain comprehension and information reconstruction tasks [6], and was shown to provide a user experience similar to using pen and paper, while still offering features not supported by pen and paper or other existing tools (e.g., direct and bimanual manipulation) [8]. More recently, OntoSketch [7] enabled non-experts to create and extend ontology knowledge by sketching diagrams and describing abstract concepts and relationships with pen and touch interaction.

Inspired by these systems, InkPlanner was designed to utilize the paper-like affordances and pen and touch interaction within a comprehensive prewriting workflow. Existing tools make it difficult to iterate on prewriting diagrams because they require the writer to complete each phase before transitioning to the next view or application in the toolchain (e.g., from *freewriting* to *mind mapping* or *concept mapping*). Unlike these tools, InkPlanner seamlessly combines different prewriting strategies in an integrated workflow. Further, these prewriting strategies do not support the process of generating presentation or telling a story, an essential step that should be undertaken before drafting. To offer a more complete workflow, InkPlanner is equipped with the novel NarrativeLine visualization widget, which helps transform user-generated diagrams into logical sequential stories. Also, unlike other tools, InkPlanner is powered by machine learning techniques that suggest content and logical structures to a writer.

3 Designing InkPlanner

3.1 Interview Study with a Writing Expert and Students

To better understand what challenges writers encounter during prewriting and what assistance may be helpful, we conducted a one-hour, in-person, semi-structured interview with the director of the Center for Academic Communication at the University of Toronto, who has over 15 years' experience doing research in written communication and teaching university-level writing courses. She developed the University's pre-writing course for graduate students and had been teaching the course for more than 5 years. The interview focused on the difficulties that students often had during prewriting, and the strategies that did or did not work for students.

To garner a different perspective on the difficulties and strategies while prewriting, we also interviewed 5 graduate students who were taking the expert's prewriting course. These students were from diverse majors, including engineering, science, and the arts, and were aged 21-30. Each student was asked to bring a diagram of their own research that they created during the prewriting class and were asked how they constructed and made use of it when drafting.

Each interview lasted about 30 minutes and was audio-taped and transcribed. The transcriptions were analysed using an open coding method [11]. Two authors coded the first 20% transcriptions and discussed them to consolidate a list of codes, which were used to code the remaining transcriptions. Disagreement was resolved through discussion. This analysis process was not intended to establish inter-rater reliability, but served to help develop our understanding of the themes in the data and the relationships among them. We obtained the following findings based on the open coding results of the transcriptions of the interviews with the expert and the students.

F1: Use a Richer Set of Prewriting Strategies

The expert noted that many students tend to plan their writing by outlining without diagramming. Two students (S1, S3) only used freewriting or outlining, and mentioned that they sometimes had trouble finding new ideas during prewriting. For students who are not experienced in writing, planning via an outline is not enough and is sometimes detrimental to the writing process, as the expert noted, "*the outline is sometimes too detailed and makes it less likely to explore more possibilities of different ideas and organizations, which constrains the thought process during prewriting*."

The diagrams that students made on paper were often hybrid maps that contained combinations of knowledge webs, mind maps, concept maps, and argument maps (S4, S5). The expert also noted that current digital diagramming tools did not support the creation of hybrid forms of diagrams that leverage multiple prewriting strategies, since most of the tools were designed for ideation and general purposes such as note-taking or information management, rather than prewriting purposes.

F2: Sequentially Sorting Ideas in Diagrams for Later Drafting

Diagramming plays an important role in organizing the ideas generated during prewriting, however, as the ideas in diagrams are often scattered, some students found it difficult to form a solid sequence of ideas while drafting (S2, S4). The expert suggested that annotating the nodes in a diagram with numbers to indicate the sequence of the nodes may be helpful. The students reflected that they, however, could easily lose track of the process. For example, S4 said that, "*Sometimes I get lost in the diagrams when drafting, as the they become too complicated or messy*." Similarly, the expert also emphasized that "*it takes time for students to master diagramming and finding the proper sequence of ideas in the diagram*."

F3: Using Pen and Paper for Ideation

The expert pointed out that "*one of the biggest challenges during prewriting was how to get the ideas out*." Using brainstorming, freewriting, and diagramming, via mind maps, concept maps, or argument maps can help students overcome writer's block. However, the expert insisted that students should prewrite using pen and paper rather than computer software because commercial tools were designed for desktop computers and students had to use a mouse and keyboard to type and organize their ideas. Based on her experience, the rigid form factor of a keyboard constrained writers' thinking. The students also expressed similar concerns about using existing computer-based tools for prewriting, either from previous negative experiences using them or preferences for using pen and paper. As S5 said, "*I find it really hard to use a desktop [computer] for prewriting. Sometimes in the worst case, I even cannot type anything*."

3.2 Design Goals

Based on the interviews with the expert and the students, we identified four overarching goals to guide the design of InkPlanner:

G1: Support Multiple Prewriting Strategies in an Iterative and Flexible Workflow

As combining different prewriting strategies improves the quality of final drafts (F1) [13], InkPlanner should seamlessly integrate multiple prewriting strategies into an iterative and flexible workflow to enable writers to freely switch between strategies as needed. The system should also provide consistent representations of text, concepts, relationships, and other metadata, which should facilitate a variety of content to be generated via different strategies.

G2: Support the Transfer of Diagrams to Logical Sequences

To bridge the gap between the scattered ideas often found in a diagram and the structured content found in a draft (F2), InkPlanner should assist the writer in finding a logical sequence to present ideas and offer suggestions of potentially meaningful sequences. This would provide writers with more useful and systematic guidance than current word processing programs do.

G3: Recommend Semantics and Structures

Finding inspiration and generating ideas is a necessary, but time-consuming task during prewriting [51]. To ease this burden and help overcome writer's block, InkPlanner should provide (i) semantic content suggestions to writers to stimulate the generation of new ideas and (ii) logical structure suggestions to help writers compose coherent stories. This would allow writers to remain engrossed in the prewriting process and foster a greater connectedness to their work.

G4: Provide Paper-like Affordances while Prewriting

Longhand writing with pen and paper leads to a better understanding of concepts and places fewer constraints on a writer's thought processes (F3) [37]. Thus, InkPlanner should support the nuances and mobility of paper and pen to enable the fluidity of brainstorming and freewriting, and the free-form nature of diagramming, while enhancing, and ultimately improving, the prewriting experience and the quality of a draft.

4 InkPlanner

Guided by the design goals, we developed InkPlanner (Figure 2), a tablet-based prewriting tool that enables a writer to utilize multiple strategies for ideation, and helps them sort ideas into logical sequences to guide drafting. InkPlanner was designed to encourage writers to *brainstorm*, *free write,* organize their ideas into a *mind map*, think about connections between ideas in a *concept map*, and develop argument structures via *argument mapping,* all in an integrated process (G1). These five prewriting strategies were chosen because they have been shown effective for improving writing quality [48], are taught in many writing courses [2], and recommended by the expert whom we consulted (F1). We also introduce *NarrativeLine*, a novel

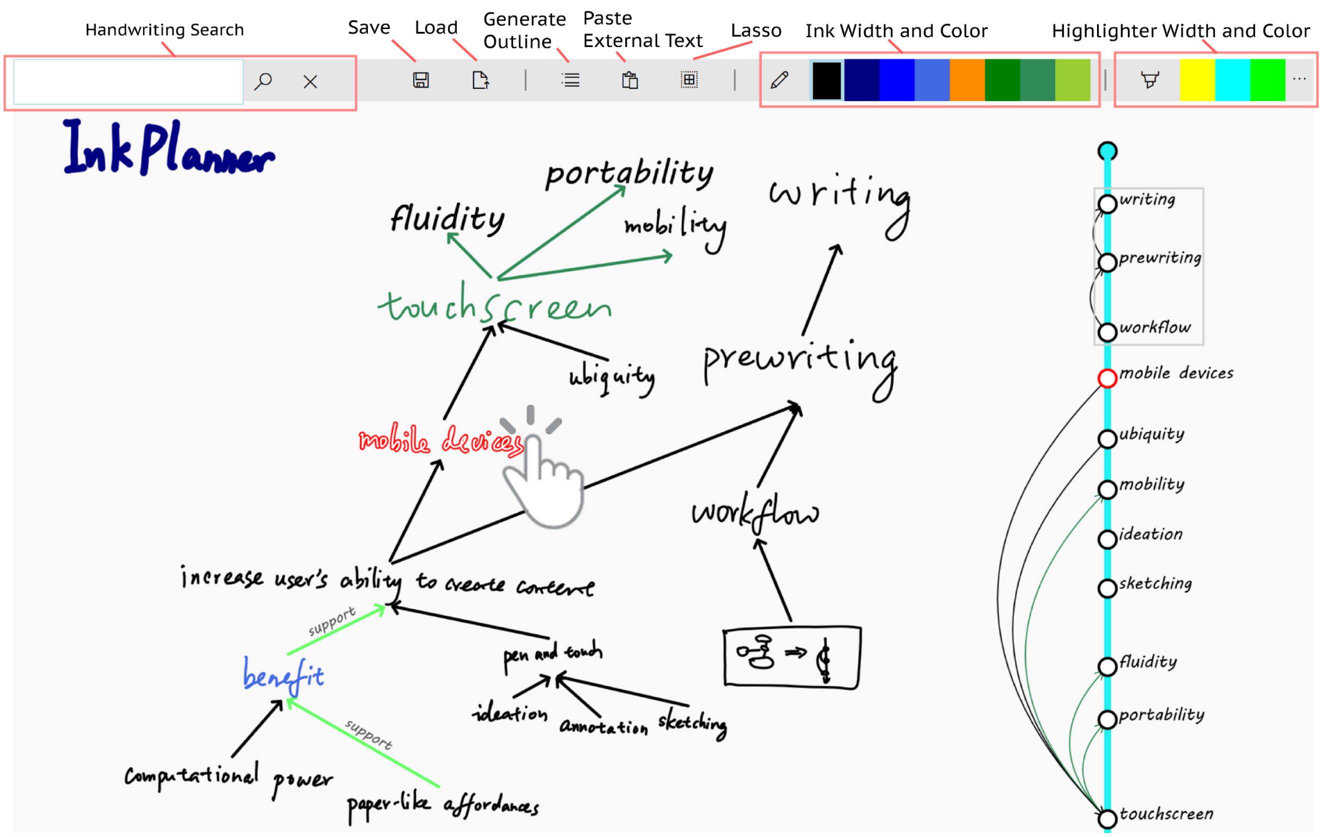


Fig. 2. A screenshot of a writer using InkPlanner to perform prewriting on the topic of "Pen and Touch Tools for Prewriting". All InkPlanner functionalities can be accessed through pen and touch gestures or via the toolbar at the top. This writer has created a diagram during idea generation (left) and a NarrativeLine (right) to sort their ideas for later drafting.

widget to support prewriting by allowing writers to transfer their diagrams of ideas into sequences of ideas (G2).

4.1 InkPlanner Workflow

While brainstorming and freewriting with InkPlanner, a writer jots down unstructured texts on the touchscreen with the pen (Figure 1). The text snippets can be manipulated via direct touch gestures to provide control over their spatial layout. The canvas is infinite and can be panned and zoomed using multi-touch gestures. The writer can organize these text snippets using a hybrid diagram of mind map, concept map, and argument map, associate them with connections, and then label the connections to indicate their different types of relationships. The tool can then guide the writer to structure all the ideas into a coherent, serialized *NarrativeLine* (G2). As more content is added, InkPlanner suggests additional content and structures using its machine learning algorithms and extensive corpus of academic writing (G3). At the end of the process, an outline can be automatically generated that can be used for drafting in a traditional word processing tool such as Microsoft Word. To generate the outline, InkPlanner outputs text snippets and relationships according to the text on the *NarrativeLine*. The hierarchy in the outline is determined by the annotations associated with the text on the NarrativeLine (Figure 1c).

Because InkPlanner is modeless and has an infinitely large canvas, writers do not have to explicitly switch between different phases of the pre-writing process and be limited to work on only one phase at any given time. Thus, the tool allows for a more iterative and flexible workflow, supporting those who pre-write in a non-linear manner (G1). For example, writers can jump directly to concept mapping from freewriting if they already have concrete ideas that are fleshed-out, without having to go through the process of mind mapping to expand their set of ideas. They can also return to mind mapping even if they have already started to build a NarrativeLine based on some of the ideas in the diagrams. The modeless design of the system also enables the writer to maintain one state within the system while accessing tools for each prewriting strategy. This allows writers to focus on the task itself, rather than discovering and remembering various system functionality while switching between different writing strategies.

4.2 Ideation with Multiple Prewriting Strategies

4.2.1 Brainstorming and Freewriting

Because brainstorming and freewriting do not require rigorous evaluations of the quality of ideas [29, 47], a writer does not need to worry whether the content they generate during these two processes is relevant or not. This helps the writer quickly become engrossed in the process of prewriting and potentially reduces the possibility of writer's block. A writer can freely write words, phrases, and sentences on the screen, which are then recognized by the handwriting recognition engine and automatically transformed into text snippets. InkPlanner recognizes these text snippets through spacing, so individual words that are within a certain distance threshold (i.e., 1.5 times the average height of the strokes) are automatically grouped to form a text snippet object. To preserve the look of the UI and make it easier for the writer to recall what they have written, the strokes are left unaltered and are not beautified. The writer can edit a text snippet by drawing a line that crosses over the original text snippet and writing new text near it. Once the new text snippet is recognized, the original text snippet will be replaced and removed, but all the connections related to the original text snippet are preserved.

4.2.2 Organizing Ideas with Diagramming

As writers begin to organize their ideas, they can utilize three different prewriting strategies, *mind mapping*, *concept mapping* and *argument mapping* to build a hybrid diagram with different types of links based on their needs (G1).

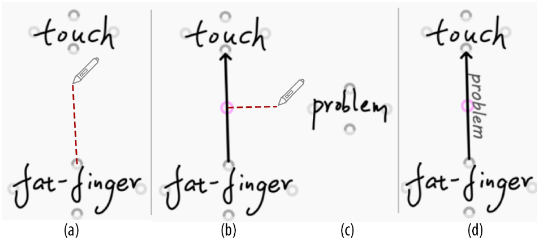


Fig. 3. Labeling an edge in a Concept Map. (a) The writer is building the connection between 'touch' and 'fat-finger' by drawing from the anchor of 'fat-finger' to that of 'touch'; (b-c) she hand-writes the label, 'problem', and draws a line from the anchor of the edge to the label, (d) the label 'problem' moves, rotates, resizes, and is shown on the edge.

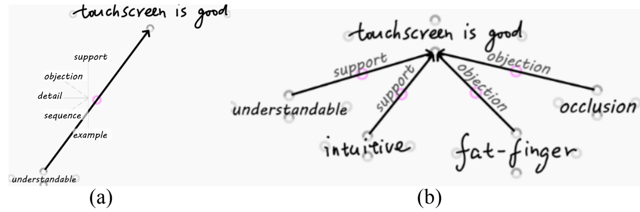


Fig. 4. (a) As the writer draws from the anchor of the connection to white space, a marking menu with five types of argument relationships appears. (b) An example of Argument Mapping.

Mind Mapping. While mind-mapping, the writer is supported in generating ideas and overcoming writer's block by the free-form pen and touch interaction. Four anchors are attached to every text snippet. These anchors are shown when the pen is hovering over a text snippet and hidden when the pen is not hovering over the text snippet. A writer can create a parent/child relationship by 'connecting the dots' between anchors. Drawing up from the top anchor builds a child-to-parent relation, whereas drawing down from the bottom anchor builds a parent-to-child relation. When the writer finishes drawing, an arrow (edge) pointing from the child to the parent is shown, indicating the relation between the two text snippets. For example, in Figure 3, drawing the line from the top anchor of "fat-finger" to the bottom anchor of "touch" creates a child-to-parent relationship between the two. Edges can be removed using the stylus' eraser. By moving text snippets around the screen, the writer can group ideas spatially. Drawing edges to connect text snippets allows the writer to associate ideas and generate new, related ideas based on the relationships that are drawn. As each edge is added, the writer can leave it unlabelled, or label it with a relationship to yield part of a concept map.

Concept Mapping. Support for concept mapping encourages writers to think about the relationships between ideas more deeply and explicitly. While concept mapping, related text snippets can be connected and the relationship between text snippets can be labelled to describe the relationship. As with mind mapping, a parent/child relationship is drawn with a directed edge. To identify the relationship between ideas, the writer can add a label to the edge. A writer can write a description in free text on the canvas, and then draw a line from the edge's anchor to the free text, which is then moved, reoriented, and resized to serve as the edge's label (Figure 3).

Argument Mapping. As argument mapping assists writers in planning the flow and argumentation of individual paragraphs and sentences [3], InkPlanner supports five types of argumentation relationships [43]: *support*, *objection*, *detail*, *sequence*, and *example*. The use of these relationships is encouraged by specific mechanisms to flesh-out writing and provide guidance to create better arguments. To build an argument map, a writer must first think carefully about the text to be written to provide sufficient information for the argument. The writer first writes their ideas in an open area of the canvas and associates them as in mind mapping. To specify an argumentation relationship, they then place their pen on an edge anchor and draw outward. A marking menu then appears and allows the writer to choose from among the five possible argumentation relationships (Figure 4a). The writer can tap on the desired relationship and the edge will be labelled with the chosen argumentation relationship.

Supporting Alternative Content. As writers sometimes sketch pictures to ideate on information or concepts during prewriting, InkPlanner also supports the creation of such content (G4). Because such sketches may also contain text, InkPlanner makes use of a bounding rectangle to delimit sketches from written content. To add alternative content, the writer first needs to draw a rectangle. The system then classifies the drawing as a sketch and the writer can add content inside the rectangle as necessary. If the writer wishes to add content from external sources, for example, Google Scholar search results, the writer can copy and paste text into InkPlanner. The pasted text is converted to a text snippet on the canvas, which can be manipulated, linked, and queried like other hand-written text snippets.

4.3 Structuring Ideas with NarrativeLines

As the writer gradually becomes more confident in the process of diagramming, they can start to plan the structure of their end document or narrative by adding text snippets from the diagrams to the *NarrativeLine*. The NarrativeLine serves as an external memory aid and assists the writer in finding a linear and logical sequence of ideas to be written during drafting. It also serves as an enhanced outline for the writer to refer to during drafting (G2).

The writer can build a NarrativeLine by drawing a vertical line on the canvas. The stroke is formalized and shown as a NarrativeLine immediately after the system recognizes the stroke (Figure 5b). The NarrativeLine can be moved or deleted using direct manipulation. Creating multiple NarrativeLines is also possible, and can be used to support the structuring of different parts of writing or for the comparison of different sequences.

The writer can add text snippets on canvas to the NarrativeLine via bimanual interaction, i.e., by long pressing a text snippet on the canvas

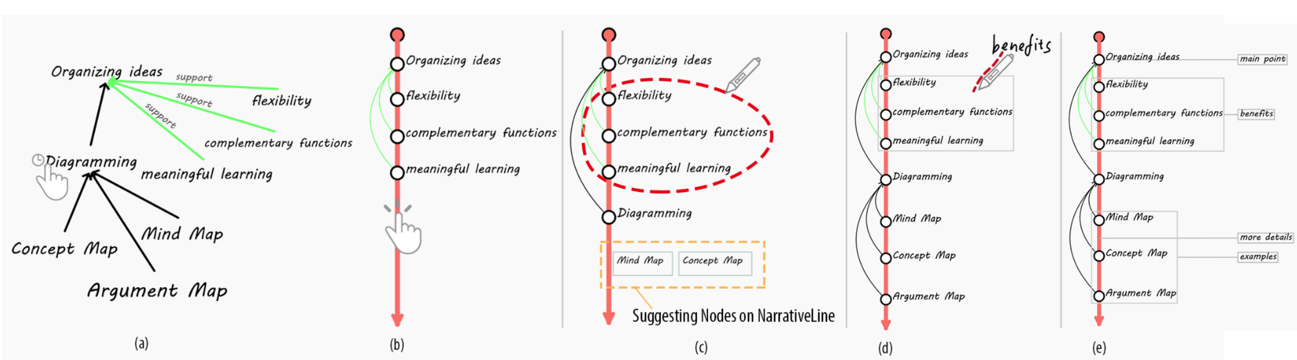


Fig. 5. NarrativeLine Interaction. (a-b) by tapping and long pressing the text snippet "Diagramming" and tapping on the NarrativeLine, "Diagramming" is attached to the NarrativeLine; (c) structural suggestions are shown after adding a node to the NarrativeLine; drawing a circle around a series of nodes creates a group; (d) an annotation can be added to a group by writing free text and drawing a line from the group to the text; (e) a NarrativeLine with annotations on nodes, groups, and segments.

with one finger to select it and tapping on the position where the node should be on the NarrativeLine with another finger to place it on the NarrativeLine (Figure 5ab). To explore different possible sequences of ideas, a writer can reorder the nodes on the NarrativeLine by moving them with their fingers.

All the links in the prewriting diagrams are visualized as arcs between corresponding nodes on the NarrativeLine. As the nodes on the NarrativeLine and the corresponding text snippets in the diagram are synchronized, long pressing one node (text snippet) will result in the corresponding text snippet (node) being highlighted. This can help a writer easily find nodes or text snippets and understand their context without searching throughout the entire screen. To help the writer determine what text snippets have not yet been added to the NarrativeLine, when long pressing on a NarrativeLine, all the text snippets on the canvas that have been already assigned to the NarrativeLine will be highlighted.

The NarrativeLine also allows writers to specify additional information. The writer can draw a circle to enclose all the nodes on a NarrativeLine that they intend to group (Figure 5c). A rectangle that encloses the nodes will appear, indicating that the nodes are grouped. A writer can still reorder the nodes within the group by dragging the nodes or add more nodes to the group by dragging an additional node into the group. The writer can also annotate a node, a group, or a segment between two nodes on a NarrativeLine, by drawing from the object that they wish to annotate towards a text snippet on the canvas (Figure 5d). The text snippet is then resized and moved to its proper position as a label on the NarrativeLine (Figure 5e).

The NarrativeLine also works seamlessly with diagramming. The writer can add text snippets to the canvas and associate them before or after creating NarrativeLines. If the writer updates connections between text snippets or edits text snippets in the diagram, the information will also be updated on the NarrativeLine.

4.4 Semantic and Structural Contextual Suggestions

Based on our consultation with the writing expert, some students frequently encounter writer's block during prewriting, and some have difficulty finding the proper structures from diagrams. To help writers overcome these issues (G3), InkPlanner supports contextual suggestions that are powered by text mining and machine learning, a component similar to that of ideaWall [52], but within the domain of writing. There are two components that provide suggestions to the writer: *Semantic Suggestions* and *Structural Suggestions*.

4.4.1 Semantic Suggestions

InkPlanner suggests content to writers to inspire them during brainstorming and to help them overcome writer's block (G2). The suggestions are based on Word2vec, a neural language model that captures the semantic context of words in an unsupervised manner, negating the need for large amounts of labelled data [36].

The current iteration of InkPlanner makes use of Word2vec vectors trained on text from academic writing to give contextual suggestions to writers. The machine learning models of these components are trained from multiple corpora, including the British Academic Written English (BAWE) corpus [39], the CATS corpus [33] and a corpus built from the text of 8,213 papers from major HCI conferences. The language models ensure that InkPlanner is aware of domain specific knowledge in formal non-fictional writing and appropriately tunes the

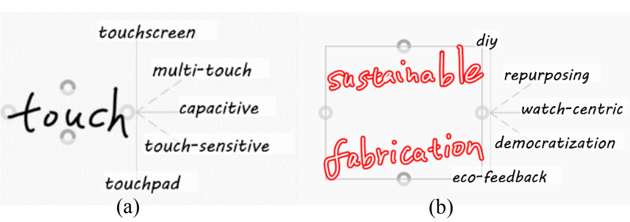


Fig. 6. Examples of semantically related words returned by *Semantic Suggestions*: (a) Results for "touch"; (b) Results for the lassoed words "sustainable" and "fabrication".

suggestions and assistance that it provides. Other corpora could be integrated in the future to support an even more diverse set of domains and possible topics.

When using InkPlanner, if the writer draws an edge from the right anchor of a text snippet to empty space on the canvas, a marking menu displays five words or phrases that are semantically related to the selected text snippet based on the Word2vec semantic suggestions (Figure 6). The semantically related words are generated by comparing the Word2vec vector of the query word or phrase with those of other words in the corpus. Cosine similarity is used to compare the similarity between words and phrases. The top five candidates are then returned and shown in the menu. The writer can use their pen to select one or more words from the menu to add them to the canvas as text snippets. The text snippets can be manipulated in the same way as a handwritten text snippet (G4). The writer can also use the newly added text snippets to see other semantically related words suggested by InkPlanner.

The *lasso* tool (Figure 2 toolbar) allows the writer to choose multiple words or phrases to query for *Semantic Suggestions* (G3). If the writer draws a circle, the text snippets within the circle are selected. The system calculates the word vector of each selected word or phrase, sums all the vectors to get a query vector, and returns the top five candidates that have the largest cosine similarity with the query vector (Figure 6b). As the machine learning techniques are corpus independent, one could utilize corpora from other disciplines to customize the recommendation engine when using InkPlanner. InkPlanner is also language model independent, so it can make use of other word embeddings [30] to give curated semantic suggestions.

4.4.2 Structural Suggestions

While the writer is adding nodes to the NarrativeLine, recommendations for other possible nodes are shown beside the NarrativeLine and beneath the last node(s) added to the NarrativeLine (Figure 5c). The writer can tap on a suggestion to add it to the NarrativeLine, or long press on a suggestion to see its location in the prewriting diagram (G4). These suggestions assist writers in composing a logical and meaningful story based on the diagrams generated by the writer.

To generate structural recommendations, text mining techniques proposed by Villalon and Calvo [57] were used to extract concept maps of all the text in the corpus. Then, the frequency of each concept followed by another concept was computed for all text in the corpus. This frequency is then used to suggest text snippets to be added to the NarrativeLine. If x_i are text snippets not yet added to the NarrativeLine, and x_{i-1}, …, x_0 are snippets already added to the Narrative Line, then the possibility that x_i will be added to the NarrativeLine is

$$p(x_i|x_{i-1},\dots,x_i) = p(x_i|x_{i-1})p(x_{i-1}|x_{i-2})\dots p(x_1|x_0)$$

The system calculates such probabilities for all the text snippets on the canvas and lists the five text snippets that have the highest possibility of being useful. The feature was designed to help writers from being constrained by text snippets that are spatially close to where they are currently working.

4.5 System Implementation

InkPlanner is a Windows Universal app written in WinJS and runs on a Microsoft Surface tablet. It uses Windows Ink API to support stylus-based handwriting and recognition. The handwriting recognition is supported by the Windows Ink API for handwriting recognition. The API returns five candidates of the recognized text of the handwriting, and InkPlanner uses the one with the highest confidence from the API. The machine learning and natural language processing algorithms were implemented in Python. The text in the corpora were pre-processed to train our own Word2vec word embeddings and model for structural suggestions based on the text. The system uses the Flask web framework to mediate communication between the interface and the backend engine for generating suggestions.

5 QUALITATIVE EXPERT REVIEW

To further understand the benefits of InkPlanner from experts' points of view, we conducted interviews with two experts. One was the writing centre director from University of Toronto whom we interviewed earlier (E1), and the other was a communication tutor from Hong Kong University of Science and Technology who has over 20 years of experience instructing English writing courses (E2).

5.1 Interview Setup

During the interview, the design concepts were introduced to the experts, followed by a demonstration of the features of InkPlanner. After introducing the features, the experts were given a walkthrough of how an academic conference rebuttal could be written with InkPlanner, to help them holistically understand how InkPlanner could be used for a writing task. The experts were then allowed to freely explore the interface and were asked to prewrite about a topic of their choice for about 15 minutes. Guidance was only provided when needed. Finally, a semi-structured interview was conducted to gain feedback on the tool's usability and utility, how each expert envisioned InkPlanner helping to generate and organize ideas during prewriting, and how they foresaw InkPlanner being used to teach students prewriting. The interviews were audio-taped, transcribed, and analysed using the same method as the previous interviews.

5.2 Results

Both experts provided positive reviews for InkPlanner. As E1 noted, "InkPlanner is a versatile pen-and-touch based computer software for prewriting, which I have not seen based on my experience using computer-based tools for prewriting". They both expressed interests in using InkPlanner in the future and even inquired about plans for releasing the tool. E2 noted, "It seems very useful and I envision it as an incredible tool for teaching prewriting. It would be great to show the prewriting process on the fly and visualize necessary information for the students."

The paper-like affordances were favoured by both experts (G4). E1 mentioned, "*the design of InkPlanner put content first, which is very important for getting ideas out during prewriting. The feeling of writing on paper also helps the writer overcome the writer's block*." E2 noted that "*it can help elderly people or novice writers who don't have enough knowledge or confidence using computer-based tools*." E2 also mentioned that the digitalized prewriting addressed problems when prewriting on physical paper, such as damaged or missing paper, and messy handwriting.

Seamlessly combining different prewriting strategies was considered a good design decision (G1). E1 noted, "*The versatility of InkPlanner is really impressive. It provides support for several of the most useful prewriting strategies in one single tool, and the writer doesn't have to switch between different tools. Students who have different preferences for prewriting can all make use of the tool*". E2 also noted that InkPlanner "*facilitates and speeds up the idea generation process*".

NarrativeLine was found to be useful in helping writers better organize ideas (G2). E1 commented, "*One prewriting diagram can be used to tell different stories by alternating the sequence of presenting ideas. The NarrativeLine makes such process easier by externalizing and visualizing the thought process and enabling comparing different NarrativeLines*." E2 noted, "*As a visual learner, I can see everything I need through the visual forms. It helps me arrange writing materials from very sketchy to very organized. With the NarrativeLine, it is easier to see where to move things around*."

For the semantic and structural suggestions, the experts had mixed feelings (G3). E1 commented, "*Although it has the potential to help novice writers, it may be harmful if they stick to it and don't think independently*." E2 mentioned, "*It is a great idea, as long as the writers take into account whether the suggestions are relevant or not*."

Both experts also suggested areas for improvement, such as offering control over the visibility of information in the diagram to reduce visual clutter, and supporting collaborative coaching so that writing instructors can guide writers face-to-face or remotely using the tool, especially for novice writers.

6 USER STUDY

To better understand how writers might use InkPlanner for prewriting, collect qualitative feedback from actual users, and assess the usability of InkPlanner in practice, we recruited users to complete a prewriting and writing session for a Graduate Record Examinations (GRE) Analytical Writing task.

6.1 Participants

We recruited 16 graduate and undergraduate students (11 females, ages 20-27) via mailing lists and word-of-mouth. All participants had at least 3 years of college-level essay writing experience and came from different academic backgrounds, including linguistics, life sciences, sociology, computer science, electrical engineering, and marketing. They each received $20 CAD for participating the study.

All participants had basic knowledge of prewriting, but their prewriting strategies varied significantly. The most popular strategies participants used were freewriting, listing, browsing, questioning, talking, mind mapping, and concept mapping. The most common media used for prewriting was pen and paper. Other media included a word processing program, or a hybrid of the pen and paper and a word processing program.

6.2 Protocol

Each participant was provided with a Microsoft Surface tablet, which was equipped with a touch screen and pen stylus for interaction. Two different topics from the GRE analytical writing section were chosen: one was about the influence of technology on human communication and the other was about the goals of research. The order of presenting the two topics was alternated between participants.

In each session, participants were given a brief introduction to InkPlanner and background about prewriting, and then a demonstration of the features available for prewriting. To avoid priming participants, we did not disclose who built InkPlanner. Next, each participant was asked to try out the features in a practice session. After becoming familiar with the system, participants were given 45 minutes to prewrite and then write on the given topic with InkPlanner. Participants were free to choose which prewriting strategies to use, although they were encouraged to try out a variety of strategies. At the end of study, participants were asked to fill out an exit questionnaire and were interviewed about their experiences using InkPlanner. The usability related questions in the questionnaire were adapted from those used in Brooke et al. [9]. We also included questions asking whether participants thought each feature of InkPlanner was helpful, on a 7-point Likert scale. Participants' interaction logs were captured, and each session was videotaped. The study lasted approximately one hour. The transcriptions of the interviews were analysed using the same method as those described previously.

Since previous studies comparing traditional media and digital diagramming tools in semester long writing classes have already shown significant improvement in students' writing skills [2], the study was not designed to compare InkPlanner to prewriting using physical pen and paper, nor to existing diagramming tools that were not designed for prewriting.

6.3 Results

To understand the usability of InkPlanner, we looked at the usability ratings of InkPlanner, how InkPlanner enhanced participant's prewriting workflows, and how participants used the NarrativeLine and semantic and structural suggestions while prewriting.

6.3.1 Usability

When asked to rate the ease of using InkPlanner to create diagrams, and the ease of learning to use InkPlanner on a Likert scale from 1-5 (1: extremely easy, 5: extremely hard), the average ratings were 2.94 (*SD: 1.20*) and 2.13 (*SD: 1.45*), respectively. It is encouraging that

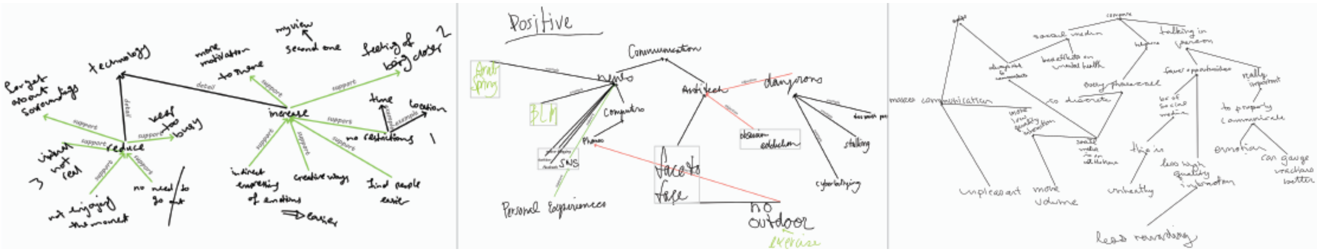


Fig. 7. Example diagrams created by participants who were prewriting about the influence of technology on human communication.

participants felt InkPlanner was easy to use, even though participants were less familiar with using pen and touch input for writing in general. (e.g. "*I prefer to use pen rather than mouse and keyboard for prewriting*" (P2), "*I felt more confident using InkPlanner than other computer-based tools I used before. Directly manipulating objects on canvas was helpful*" (P7)).

Participants also rated their self-perceptions of their prewriting, and their final output using features of InkPlanner on a 7-point Likert scale (1: strongly disagree, 7: strongly agree). The results demonstrated that participants felt that InkPlanner was: fun to use ($Median$ = 6, IQR = 2); engaging while making diagrams of ideas ($Median$ = 6, IQR = 1); and engaging while making NarrativeLines ($Median$ = 6, IQR = 2). Participants also reported the following features of InkPlanner to be very helpful on a 7-point scale (1: not at all helpful; 7: extremely helpful): direct manipulation ($Median$ = 6, IQR = 1), building connections ($Median$ = 6, IQR = 0.75), and labelling the connections in diagram ($Median$ = 6, IQR = 2).

All participants agreed that it would be great to use InkPlanner for prewriting in the future. As P7 noted, "*It is easy to get started, and I think if I get more familiar with the system, it would benefit my prewriting and writing more*."

6.3.2 Prewriting Workflows

When using InkPlanner, participants wrote down ideas, organized them using diagramming (clustering), and kept iterating on their diagrams (Figure 7). Participants seldom experienced writer's block while using InkPlanner, i.e., "*I personally like writing ideas down more than typing them out. I found ideas came to me more easily and the quality of the idea was better when I was writing*" (P4) and "*InkPlanner activated more ideas, since I tend to write short snippets, which placed less constraints and can inspire me of more ideas*" (P8). These comments illustrate the benefits of supporting prewriting with paper-like affordances, pen interaction (G4), and a combination of prewriting strategies (G1).

While using InkPlanner, participants wrote words, phrases, or short sentences, which encouraged them to explore other ways to convey their ideas, i.e., "*When using InkPlanner, although I wrote shorter, I think deeper about what I wrote down and sometimes even came up with new ideas based on that*" (P8). The non-beautified form of handwriting also maintained more information and reminded the writer of their thought processes, e.g., "*I can easily remember what I was thinking about during diagramming when I see my own handwriting*" (P15).

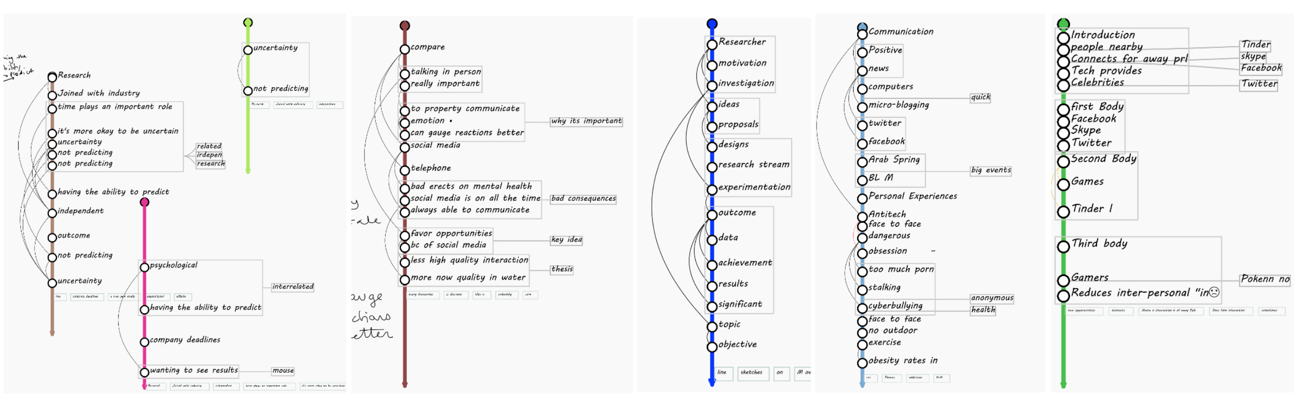
Ten participants also noted that they felt that they wrote more quickly using InkPlanner than without, e.g., "*I think I wrote faster with InkPlanner, since the content and structure became clearer in my mind after prewriting*" (P1).

6.3.3 NarrativeLines

In general, participants liked using the NarrativeLines ("*I enjoyed using NarrativeLine. When I do prewriting I am a bit unorganized. The NarrativeLine helps me to organize my ideas better and more quickly*" [P16]; "*NarrativeLine was useful. It helped me layout my ideas, kept me in track and avoid repeating*" [P10]; Figure 8). Based on a 7-point scale, participants felt that NarrativeLine was helpful while: exploring other ways of organizing arguments ($Median$ = 6, IQR = 2), organizing arguments ($Median$ = 6, IQR = 0), and composing a better-quality essay ($Median$ = 6, IQR = 1). They also felt that annotating on the NarrativeLine was helpful ($Median$ = 6, IQR = 1).

All the participants created at least 1 NarrativeLine and added, on average, 13 text snippets to each NarrativeLine. They reordered or deleted text snippets on the NarrativeLine an average of 15 times, built an average of 3 groups of text snippets on each NarrativeLine, and added an average of 3 annotations to each NarrativeLine. Ten participants iterated on their diagrams after creating a NarrativeLine. "*I came up with some more ideas during building the NarrativeLine, so I came back to the diagrams and add more content to it*" (P3). This indicates that the modeless design of InkPlanner supported writers in seamlessly iterating on prewriting as their process and ideas evolved.

While drafting, 12 participants focused almost exclusively on the NarrativeLines they built, only referring occasionally to the diagrams they created during prewriting. The other four only referred to their diagrams while drafting. Participants agreed that the diagrams and NarrativeLines provided different functions, "*the NarrativeLine is more concrete and serves as a summary of the diagrams, and it contains more information about structure. It can easily remind me of my ideas and their sequence with a glance; when I need to know more*



(a) (b) (c) (d) (e)

Fig. 8. Example NarrativeLines created by participants, showing different practices: (a) using multiple NarrativeLines; (b) one NarrativeLine with very detailed information; (c) one NarrativeLine with concise information; (d) using annotations to add information to a NarrativeLine; (e) directly embedding structural information into a NarrativeLine.

details, I would navigate to the diagram and it reminds me of what my ideas were and the context" (P8, G3). Those who did not refer to NarrativeLines much during drafting did, however, mention that NarrativeLine was helpful. "*After using NarrativeLine I already had a clear structure in mind, so I just referred to the diagram for details during drafting. But if the task is more complicated, I would definitely refer to the NarrativeLine more*" (P15).

6.3.4 Semantic and Structural Suggestions

Through the analysis of the log data, the average number of text snippets on the canvas that were generated through semantic suggestions was 3.19 (*SD* = 6.34, *Range* = 0-27), and the average number of nodes added to NarrativeLine through structural suggestions was 7.31 (*SD* = 5.70, *Range* = 0-22). As there was a large variance in adopting the suggestions, this may be the reason why semantic and structural suggestions received mixed reviews.

Suggesting nodes on the NarrativeLine was perceived as helpful (*Median* = 6, IQR = 1), "*The suggestion for upcoming nodes on the NarrativeLine helped me to find a better sequence of presenting the ideas quickly and conveniently*" (P8). Seven participants agreed that the suggested content inspired them, e.g., "*the application did enable me to get some new ideas that I would have had to search intensively before coming to*" (P5). Opinions about suggesting semantically related words were mixed (Median = 4.5, IQR = 3), with 7 participants agreeing that they were helpful, 6 disagreeing, and 3 remaining neutral. Five participants reported that they were inspired by some of the suggested words, as noted by P5, "*Sometimes although the words were not directly related with my ideas, they really inspired me to come up with some new ideas, and made me feel like looking into the corpus to see why these words are semantically related*" (G2).

By observing how the participants use suggestions for content, it was found that their attitudes about the suggested content were influenced by their practice using InkPlanner. Those finding it helpful were the ones who tried to use the suggestions more, while those disagreed were the ones who seldom or never used the suggestions. Since the suggestions were designed to be non-intrusive and the system only provides suggestions when the writer asks it to, it is likely that some participants forgot about the suggestions and hence, did not actively explore these suggestions. This non-intrusive way of showing suggestions was, however, liked by the participants. "*The way suggestions show up only when I need them makes me undistracted during thinking; however, [InkPlanner] is ready to help me whenever I encounter the writer's block*" (P8). The suggested content was also found to have the potential to be more helpful in the drafting phase, when a user needs to find specific words for certain concepts, as noted by P4, *"on a writing stage (not mind map stage), I would find it very useful to have these semantically related words.*" This indicates that the suggestions generated by InkPlanner have the potential to support the entire writing process.

7 Discussion and Future Work

InkPlanner provided beneficial support for prewriting as indicated through the expert reviews and the user study. Given the short time that participants were exposed to InkPlanner and the difficulty that many writers have with the writing process in general, the results of the study are encouraging. We thus believe that a deployment study of InkPlanner with a larger group of users for a longer period could reveal InkPlanner's long-term impact on writing. The studies and interviews revealed a number of potential future directions to further improve the prewriting support of InkPlanner.

7.1 Supporting Drafting Process

InkPlanner supports the prewriting process through freeform diagramming and NarrativeLines, but does not support drafting with the same depth of support. Consequently, participants had to refer to their NarrativeLines and diagrams while drafting. Future research should explore how to extend InkPlanner to support the entire writing process. For example, based on the content created in InkPlanner, it would be beneficial to remind writers about the ideas that have not yet been integrated into a draft or alert them when the logical order of sentences is inconsistent with those in their NarrativeLine. InkPlanner currently allows writers to reuse a diagram or a NarrativeLine created prior by importing it into the workspace. Similarly, reusing existing resources (i.e., importing a publication and extracting its structure automatically while reusing the content and the structure) could be useful to explore further, as it could enable novice writers or those enrolled in academic writing courses to learn from established content.

7.2 Authorship and Authenticity

Participants had varied opinions on the relevance of the machine generated suggestions, however, the quality of suggestions will likely improve as machine learning and natural language processing techniques continue advancing. As suggestions become more relevant, issues of authorship may become increasingly pertinent. Academic writers hold their publications and ideas in high regard and one needs to be mindful to not over-suggest ideas or enable for the automatic generation of entire bodies of content. As automatically generated text removes some of the personalization inherent in the writing process, it can quickly lead to questions about authorship and authenticity. It is thus important to weigh the degree of assistance that suggestions can provide to a writer.

7.3 Flexibility, Generalizability, and Limitations

Although multiple NarrativeLines could be created to support documents longer than essays, with different NarrativeLines representing different parts of the documents, it would be challenging to efficiently manage many NarrativeLines. Future research should explore how to help users when prewriting for long documents, that could have thousands of nodes or diagrams, such as theses or book chapters. Because InkPlanner naturally supports multiple prewriting strategies, it could help writers in the early stage of a project by supporting idea generation, assisting them in performing a literature review, finding potential research questions, or managing their knowledge in a certain domain. The visual diagrams can also serve as a medium by which people share their early stages of writing or research projects, to get feedback from experts and peers when it might be most useful. A user modelling and personalization engine could also be developed to track research interests across projects and provide customized suggestions to the user. It could also be useful for the system to interface with other research tools, such as reference managers or Digital Libraries, to extract information and metadata that may be consulted while writing a manuscript.

8 Conclusion

This work explored the creation of a digital tool to assist with the important process of prewriting. We first conducted a design study with writing experts and student learners to understand current prewriting processes. The findings informed the design of InkPlanner, an integrated visualization tool that allows writers (i) to utilize five prewriting strategies in an interleaved manner, (ii) to organize ideas via visual diagramming and (iii) structure these ideas into a linear logical order for later drafting. InkPlanner employs pen-and-touch interaction, a NarrativeLine widget, and machine-generated suggestions to assist writers in seamlessly generating and organizing ideas in one integrated workflow. The results of expert interviews and a user study demonstrated that InkPlanner encourages visual thinking, inspires writers to generate more ideas, helps with the organization of ideas into logical sequences, and provides meaningful information that can be referred to later, while drafting a narrative or manuscript.

Acknowledgments

The authors wish to thank Dr. Jane Freeman, Dr. Fanny Chevalier, Dr. Daniel Avrahami, and the reviewers for their valuable comments, and the experts and the participants for their contributions to this work. This work was supported in part by a grant from NSERC.

REFERENCES

[1] S. Abbott, “Talking It Out: A Prewriting Tool,” *English J.*, vol. 78, no. 4, pp. 49–50, 1989.

[2] S. Afshari and H. Salehi, “Effects of using Inspiration software on Iranian EFL learners’ prewriting strategies,” *Int. J. Res. Stud. Educ. Technol.*, vol. 6, no. 2, Feb. 2017.

[3] M. A. Barnett, “Writing as a process,” *French Rev.*, vol. 63, no. 1, pp. 31–44, 1989.

[4] I. Baroudy, “A Procedural Approach to Process Theory of Writing: Pre-writing Techniques,” *Int. J. Lang. Soc. Cult.*, vol. 24, 2008.

[5] A. Bharath and S. Madhvanath, “FreePad: a novel handwriting-based text input for pen and touch interfaces,” in *Proceedings of the 13th international conference on Intelligent user interfaces*, 2008, pp. 297–300.

[6] M. Brade, C. Brändel, A. Salmen, and R. Groh, “SketchViz: A Sketching Interface for Domain Comprehension Tasks Illustrated by an Industrial Network Use Case,” in *Proceedings of the 12th International Conference on Knowledge Management and Knowledge Technologies*, 2012, p. 30:1--30:4.

[7] M. Brade, F. Schneider, A. Salmen, and R. Groh, “OntoSketch : Towards Digital Sketching as a Tool for Creating and Extending Ontologies for Non-Experts,” *Int. Conf. Knowl. Manag. Knowl. Technol. 2013*, p. 9:1-9:8, 2013.

[8] M. Brade, A. Sehl, and R. Groh, “Between the Lines: A Comparative Study of Freeform-Based Knowledge-Map-Creation with Paper and Tablet,” in *Proceedings of the 2016 CHI Conference Extended Abstracts on Human Factors in Computing Systems*, 2016, pp. 3006–3012.

[9] J. Brooke and others, “SUS-A quick and dirty usability scale,” *Usability Eval. Ind.*, vol. 189, no. 194, pp. 4–7, 1996.

[10] T. Buzan and B. Buzan, The Mind Map Book: How to Use Radiant Thinking to Maximize Your Brain’s Untapped Potential. New York: Plume, 1993.

[11] J. Corbin and A. Strauss, “Basics of qualitative research: Techniques and procedures for developing grounded theory,” 2008.

[12] T. J. Cossairt and J. J. LaViola, “SetPad: A Sketch-Based Tool For Exploring Discrete Math Set Problems,” in *International Symposium on Sketch-Based Interfaces and Modeling*, 2012, pp. 47–56.

[13] M. Davies, “Concept mapping , mind mapping and argument mapping : what are the differences and do they matter ?,” *High. Educ.*, vol. 62, no. 3, pp. 279–301, 2011.

[14] C. P. Dwyer, M. J. Hogan, and I. Stewart, “The evaluation of argument mapping as a learning tool: Comparing the effects of map reading versus text reading on comprehension and recall of arguments,” *Think. Ski. Creat.*, vol. 5, no. 1, pp. 16–22, 2010.

[15] J. Emig, “Writing as a mode of learning,” *Coll. Compos. Commun.*, vol. 28, no. 2, pp. 122–128, 1977.

[16] M. J. Eppler and L. Usi, “A comparison between concept maps , mind maps , conceptual diagrams , and visual metaphors as complementary tools for knowledge construction and sharing Correspondence :,” *Inf. Vis.*, vol. 5, no. 3, pp. 202–210, 2006.

[17] H. Faste and H. Lin, “The untapped promise of digital mind maps,” in Proceedings of the 2012 ACM annual conference on Human Factors in Computing Systems - CHI ’12, 2012, p. 1017.

[18] J. Fernquist, T. Grossman, and G. Fitzmaurice, “Sketch-sketch revolution: an engaging tutorial system for guided sketching and application learning,” in *Proceedings of the 24th annual ACM symposium on User interface software and technology - UIST ’11*, 2011, p. 373.

[19] Florida Institute for Human & Machine Cognition (IHMC), “Cmap Software.” .

[20] L. Flower and J. R. Hayes, “A cognitive process theory of writing,” *Coll. Compos. Commun.*, vol. 32, no. 4, pp. 365–387, 1981.

[21] A. V. Gonzalez, “SketChart: A Pen-based Tool for Chart Generation and Interaction,” University of Central Florida Orlando, Florida, 2014.

[22] Y. Guiard, “Asymmetric division of labor in human skilled bimanual action: The kinematic chain as a model,” *J. Mot. Behav.*, vol. 19, no. 4, pp. 486–517, 1987.

[23] K. Hinckley et al., “Pen+ touch= new tools,” in Proceedings of the 23nd annual ACM symposium on User interface software and technology, 2010, pp. 27–36.

[24] K. Hinckley *et al.*, “InkSeine: In Situ search for active note taking,” in *Proceedings of the SIGCHI conference on human factors in computing systems*, 2007, pp. 251–260.

[25] J. I. Hong and J. A. Landay, “SATIN : A Toolkit for Informal Ink-based Applications,” in *ACM Symposium on User Interface Software and Technology*, 2000, pp. 63–72.

[26] G. Johnson, M. D. Gross, J. Hong, and E. Y.-L. Do, “Computational Support for Sketching in Design: A Review,” *Found. Trends Human-Computer Interact.*, vol. 2, pp. 1–93, 2009.

[27] R. T. Kellogg, “Effectiveness of Prewriting Strategies as a Function of Task Demands,” *Am. J. Psychol.*, vol. 103, no. 3, pp. 327–342, 1990.

[28] B. Lee, R. H. Kazi, and G. Smith, “SketchStory : Telling More Engaging Stories with Data through Freeform Sketching,” in *IEEE Transactions on Visualization & Computer Graphics*, 2013, vol. 19, no. 12, pp. 2416–2425.

[29] I. Leki, Academic writing: Exploring processes and strategies. Cambridge University Press, 1998.

[30] O. Levy and Y. Goldberg, “Dependency-based word embeddings,” in Proceedings of the 52nd Annual Meeting of the Association for Computational Linguistics (Volume 2: Short Papers), 2014, vol. 2, pp. 302–308.

[31] M. Liu, R. A. Calvo, S. Member, A. Aditomo, and L. A. Pizzato, “Using Wikipedia and Conceptual Graph Structures to Generate Questions for Academic Writing Support,” *IEEE Trans. Learn. Technol.*, vol. 5, no. 3, pp. 251–263, 2012.

[32] M. Liu, R. A. Calvo, and V. Rus, “Automatic Question Generation for Literature Review Writing Support,” *Lect. Notes Comput. Sci.*, 2006.

[33] A. Louis and A. Nenkova, “What Makes Writing Great? First Experiments on Article Quality Prediction in the Science Journalism Domain,” *Trans. Assoc. Comput. Linguist.*, vol. 1, pp. 341–352, 2013.

[34] S. Marcus and S. Blau, “Not Seeing Is Relieving: Invisible Writing with Computers.,” *Educ. Technol.*, vol. 23, no. 4, pp. 12–15, 1983.

[35] J. E. McGlinn and J. M. McGlinn, “Problem Solving And Prewriting; Mental Play in the Writing Class.,” 1990.

[36] T. Mikolov and J. Dean, “Distributed representations of words and phrases and their compositionality,” *Adv. Neural Inf. Process. Syst.*, 2013.

[37] P. A. Mueller and D. M. Oppenheimer, “The pen is mightier than the keyboard advantages of longhand over laptop note taking,” *Psychol. Sci.*, p. 0956797614524581, 2014.

[38] J. Müller and D. Polansky, “FreeMind - free mind mapping software.” .

[39] H. Nesi, G. Sharpling, and L. Ganobcsik-Williams, “Student papers across the curriculum: Designing and developing a corpus of British student writing,” *Comput. Compos.*, vol. 21, no. 4, pp. 439–450, 2004.

[40] J. D. Novak and D. Musonda, “A twelve-year longitudinal study of science concept learning,” *Am. Educ. Res. J.*, vol. 28, no. 1, pp. 117–153, 1991.

[41] S. T. O’Rourke and R. A. Calvo, “Visualizing Paragraph Closeness for Academic Writing Support,” in *2009 Ninth IEEE International Conference on Advanced Learning Technologies*, 2009, pp. 688–692.

[42] S. T. O’Rourke, R. A. Calvo, and D. S. Mcnamara, “Visualizing Topic Flow in Students’ Essays,” in *Educational Technology & Society*, 2013, vol. 14, no. 3, pp. 4–15.

[43] A. Peldszus and M. Stede, “From argument diagrams to argumentation mining in texts : a survey,” *Int. J. Cogn. Informatics Nat. Intell.*, vol. 7, no. 1, pp. 1–31, 2013.

[44] F. Perteneder, M. Bresler, E.-M. Grossauer, J. Leong, and M. Haller, “cLuster: Smart Clustering of Free-Hand Sketches on Large Interactive Surfaces,” in *Proceedings of the 28th Annual ACM Symposium on User Interface Software & Technology*, 2015, pp. 37–46.

[45] R. Pishghadam and A. Ghanizadeh, “On the impact of concept mapping as a prewriting activity on efl learners’ writing ability.”

[46] ReasoningLab, “Rationale: better thinking, clearer writing.” .

[47] J. M. Reid, *The process of composition*, vol. 1. Prentice Hall, 1988.

[48] A. Reima, “Enhancing Freshman Students’ Writing Skills with Mind-Mapping Software,” in *The 5th International Scientifics Conference--eLearning and Software for Education--Bucharest*, 2009.

[49] G. L. Rico and J. P. Tarcher, “Writing the natural way: Using right-brain techniques to release your expressive power,” *Los Angeles JP Tarcher*, 1983.

[50] D. G. Rohman, “Pre-Writing the Stage of Discovery in the Writing Process,” *Coll. Compos. Commun.*, vol. 16, no. 2, pp. 106–112, 1965.

[51] J. Sadauskas, S. M. Ave, D. Byrne, R. K. Atkinson, and S. M. Ave, “Mining Memories : Designing a Platform to Support Social Media Based Writing,” in *Proceedings of the 33rd Annual ACM Conference on Human Factors in Computing Systems*, 2015, pp. 3691–3700.

[52] Y. Shi, Y. Wang, Y. Qi, J. Chen, X. Xu, and K.-L. Ma, “IdeaWall: Improving Creative Collaboration Through Combinatorial Visual Stimuli,” in *Proceedings of the 2017 ACM Conference on Computer Supported Cooperative Work and Social Computing*, 2017, pp. 594–603.

[53] G. E. M. Stapleton, B. Plimmer, A. Delaney, and P. Rodgers, “Combining Sketching and Traditional Diagram Editing Tools,” *ACM Trans. Intell. Syst. Technol.*, vol. 6, no. 1, pp. 1–29, 2015.

[54] I. E. Sutherland, “Sketch pad a man-machine graphical communication system,” in *Proceedings of the SHARE design automation workshop*, 1964, pp. 6–329.

[55] M. Uto and M. Ueno, “Academic Writing Support System using Bayesian Networks,” in *IEEE International Conference on Advanced Learning Technologies*, 2015, pp. 385–387.

[56] J. Villalón, P. Kearney, R. A. Calvo, and P. Reimann, “Glosser: Enhanced Feedback for Student Writing Tasks,” in *2008 Eighth IEEE International Conference on Advanced Learning Technologies*, 2008, pp. 454–458.

[57] J. Villalon and R. A. Calvo, “Concept Maps as Cognitive Visualizations of Writing Assignments,” *Educ. Technol. Soc.*, vol. 14, no. 3, pp. 16–27, 2011.

[58] M. Wang, B. Plimmer, P. Schmieder, G. Stapleton, P. J. Rodgers, and A. Delaney, “SketchSet: Creating Euler diagrams using pen or mouse,” in *IEEE Symposium on Visual Languages & Human-centric Computing*, 2011, pp. 75–82.

[59] R. Zeleznik, A. Bragdon, F. Adeputra, and H.-S. Ko, “Hands-on Math: A Page-based Multi-touch and Pen Desktop for Technical Work and Problem Solving,” in *Proceedings of the 23Nd Annual ACM Symposium on User Interface Software and Technology*, 2010, pp. 17–26.

[60] “iMindMap: Mind Mapping and Brainstorming Software.” [Online]. Available: https://imindmap.com/.