Aiding Memory Recognition Using Framework Building for Aphantasia

A Machine Learning Web Extension

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Program Statement on the Master of Graphic Design Final Project

This document details a final project, which in design is commonly referred to as a graduate "thesis," at North Carolina State University. The work was defined in a 3-credit course in a fall semester, and executed in a 6-credit course in the following spring semester. The Master of Graphic Design is a terminal professional degree with a research orientation, but like the MFA and MDes, it is not a primary research degree. This is a discovery-based investigation. Cash (2018) describes the process of building scientific knowledge as a cycle between theory building and theory testing. The theory building mode includes (1) discovery and description, (2) definition of variables and limitation of domain, and (3) relationship building (pp. 88–89). This investigation is restricted to the theory building mode. The theory testing mode includes (4) prediction, testing, and validation, and (5) extension and refinement (p. 89). While experts may have been consulted, this investigation does not entail any testing with human subjects, and it does not endeavor to prove anything; all assertions are tentative and speculative.

See: Cash, P. J. (2018). Developing theory-driven design research. *Design Studies*, 56, 84–119.

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Abstract

Aphantasia is a rare way to cognitively perceive the world that involves the inability of people to see things within the mind's eye. An estimated 2% of the population has aphantasia, which affects major cognitive processes like episodic memory, future event prospection, visual working memory, and dreaming. Even with cognitive processes like this disrupted, those with aphantasia have learned ways around it by developing their own internal toolsets and relying on associations they have accumulated. Aphantasia is underrepresented despite the recent shift for inclusive design and has room for many future assistive tools and technology to aid this population as research and understanding grows. This investigation aims to create a web extension to aid associative memory retention in individuals with aphantasia by augmenting a user's visual perception of an academic paper as well as providing a framework-building tool to capitalize on spatial memory.

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Acknowledgments

First off, I would like to thank those who have been with me from the beginning of my MGD journey: Ab, Angel, Ashamsa, Gloria, Matthew, Matty, and Syashi. Thank you all from the bottom of my heart for seeing something in me in those early days and sticking around, even venturing as far as to befriend me outside of what was academically required. While a few of us have lost connection, your importance to me still remains the same.

Attending graduate school and writing a thesis is very difficult and I am eternally grateful to my family for working with me no matter the stressor thrown my way.

I all but disappeared from reality to my friends during graduate school, and I cannot express how wonderful it is to have you, Ana and Melissa, as my best ones, sticking with me even when I was so caught up in work my messages were rather inconsistent.

I would be remiss not to mention the importance of Matthew Peterson as both my thesis chair, but also as a guiding light and voice of reason to me these past few years. Those are some wonderful superpowers you have.

Thank you to my MGD peers (before, during, and after me) and professors for building an environment that allowed me to challenge myself as a designer and an individual to become more confident in who I am. None of this would have been possible without your feedback.

I would also like to thank one of my closest confidants throughout my entire thesis journey. Thank you for your love and support.

Thank you to those special people who listened to every idea and supported me, encouraging me to keep going even when I thought I was at a wall. Your importance has been something otherworldly and my thesis would not have been possible without the attention and care you all provided.

And finally, to the person reading this, thank you.

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1
INTRODUCTION

The concept of having an imagination has been long debated, but it was not until recently that science revealed that there were differences in the way people cognitively "imagine" things. In fact, most people fall under a variation of phantasia, where they can picture objects and ideas in their mind, with variations in how prominent or detailed the visuals are. Those who are unable to visualize voluntarily within their mind's eye, or inner thoughts, have aphantasia. Aphantasia is a term used to describe an individual who cannot see anything when they close their eyes. For example, if one is tasked with imagining an apple, do they see something? How detailed is it? Is it just an outline or a recognizable object? Can a bite be taken out of it? People with aphantasia rely on their associations for imagination, building off of their grounded knowledge rather than reflecting visually on information. They can still draw the apple even with a bite taken out of it, but only when given a prompt, not because it is something they manifest within their minds.

As this topic continues to be researched, a pressing issue is emerging: learning. There are already different ways of learning that have been researched throughout the years, and people who have aphantasia can work with a few of these pedagogies, but they must invest time adapting to each situation that does not consider the lack of internal visualization. So the question can then be asked: how can accessible technologies aid people with aphantasia in retaining information?

2

PROBLEM SPACE

2.1   Problem Statement

It is estimated that 2% of the population has some form of aphantasia (Zeman et al., 2015). To date, aphantasia is shown to be a stable state and not a variable state (Zeman et al., 2016). This means that the condition of having aphantasia does not necessarily waver and is rather consistent in people's day-to-day lives. It is important to note that aphantasia already lies within a spectrum of phantasia, ranging from aphantasia to hyperphantasia (Pearson, 2019). Within aphantasia specifically, there may be many groups of people with varying cases of severities and conditions (Dawes et al., 2020). For example, it was found that a majority of people develop aphantasia throughout their lives, as only a few have lacked visual thought since birth (Dawes et al., 2020). The development of aphantasia leads to interesting implications on trauma responses with episodic memory and the potential for exploring defense mechanisms within the brain. It was also found that a majority of people with aphantasia have reported that they only experience visual mental imagery loss, though there is a rather large portion who experiences multi-sensory loss (Dawes et al., 2020). This investigation addresses people who only lack visual mental imagery and not an extra sensorial loss.

Having the ability to visualize things within one's mind contributes to essential cognitive processes like episodic memory, future event prospection, visual working memory, and dreaming (Dawes et al., 2020). However, those with aphantasia have reduced, if not nonexistent, abilities in these essential cognitive processes due to a lack of the mind's eye (Dawes et al., 2020). This is not to say that those without visual mental imagery are not able to work with visuals; they just use a different toolset when approaching problems ("Learning with Aphantasia," 2019). Those with physical impairments hone in on other skills and senses to interact with the world around them. With impairments that cannot be seen, those toolkits are still being understood, and therefore calls for design interventions. It is possible that people with aphantasia, while unable to playback visual information, can still retain it as a reference point to call upon when seeing a visual cue.

Studies have shown that a trigger for long-term memory concerns a target, or contextual cueing, to efficiently search information (Nickel et al., 2020). Once the target has been found, people often single out that cue to process it further (Vierck & Miller, 2005). A cue is anything that acts as an indicator to something or someone else, such as, size, shapes, color, and placement. These cues can be stronger in feature combinations, such as spatial location, color, shape, and text, and in turn generate a slow yet stronger long-term memory (Shimi & Logie, 2018). This means that repeated or established cues can help long-term memory recognition. The act of retrieving this information from long-term memory via a cue can increase the probability of success in remembering (Sutterer & Awh, 2015). The most successful cues from people with aphantasia seem to be space, shape, and color. These instances may call upon mental imagery, yet still, deny

the person of voluntary imagery to complete the task. Spatial ability, such as spatial imagery and navigation, is a feature that people with aphantasia do not struggle with (Dawes et al., 2020). Spatial cues have the highest chance of success in a target memory recognition cue, with color following in success rate (Vierck & Miller, 2005). When these combinations are associated with an object or shape that has meaning to an individual, the relationships and associations one has built create an easier chance to recognize.

One of the first stimuli for learning as a child is visual, as one does when looking at a picture book and identifying the imagery. The focus here is not whether they can picture a tiger in their mind, but rather that they can identify it; or whether they can associate a word like "mama" to the face of their mother. These skills are still intact for people with aphantasia; the difference then becomes when they are asked to detail, imagine, or visualize said association. Along with early education, humans learn to associate, talk, and explore before learning to read or write. This distinct separation in developmental time alludes to a higher level of complexity in the latter two tasks. When faced with so much information conveyed through a systemic format of writing and language, these complex tasks can become harder when one cannot use their other senses to embrace text. The processing of literature usually becomes a problem when documents such as textbooks, books, and research papers are put into a digital format, as the other ways of interaction and building memory are strictly based on the words themselves.

When put into situations where sight-reliant text is the only indicator for memory, online educational material can prove lackluster in building a connection between a person and the material. There has been an effort to make digital tools more accessible and inclusive by nature, such tools are not universal to every website, and none consider those with aphantasia. Evidence indicates that people with aphantasia adapt to the situation around them. However, visual mental imagery is a toolset that helps humans understand the world around them and draw connections (Dawes et al., 2020). So, how can one with aphantasia build these relationships with text, such as research papers? The answer is by accessing other aspects of sight to trigger memory retention. Visual cues have been used for as long as humans have attempted communication to portray an idea. While unable to draw upon these visual cues within their mind, researchers speculate that those with aphantasia still use mental imagery in a different way (Jacobs et al., 2017). Associations that have been established in understanding a cue could still build a relationship that aids the ability to recognize information.

2.2 Justification

This investigation explores potential tools to aid aphantasics' processes and make complex tasks easier. There are already many ways to acknowledge and work with different learning techniques. As we learn just how complex humans can be, if a condition impedes the ability to learn, then tools should exist to assist as well.

Examples of accessible tools include dyslexic typefaces, text to speech readers, digital reader helpers, or machine learning algorithms. Accessibility tools are not designed to alienate a user, and usually are non-obtrusive in design. An example of a non-obtrusive web extension would be one aimed to have a user navigate through a website using only their voice, aiding people with visual impairments (Pérez, 2019). Several different web-based accessibility programs are available that aim to augment an individual's experience so they may continue their task unimpeded (Ok & Rao, 2019).

There are tools that while not initially aimed at accessibility, increase efficiency in a given task. Examples include data extraction tools that extract raw text or data of a given location and compile them into a separate location. Several of these tools can be applied to formats, like research papers, that have a rather consistent uniformity to them (Corney et al., 2004).

Some helper tools not only increase efficiency but also accessibility through personalization. A data extractor tool was programmed to not only text mine, but also provide reading assistance, allowing the user a smoother experience within a very specific database (Chen & Ho, 2014). A successful example of an efficient accessibility tool for online-based math uses visual cues to aid users based on their math literacy levels (Cervone & Sorge, 2019).

In regards to aphantasia, the problem then becomes a matter of finding out what methods of accessibility are the most successful and assembling them into a cohesive format. Understanding and supporting aphantasia becomes a designer's problem to look at how one might approach a complex task and designing a system that aids the speed at which one can successfully get through and retain the information they are working with.

2.3   Annotated Bibliography

Understanding aphantasia. The following sources were used to extract information on defining aphantasia and how it functions.

A *cognitive profile of multi-sensory imagery, memory and dreaming in aphantasia* was an investigative study using three test groups that looked into what cognitive processes are affected when one has aphantasia (Dawes et al., 2020). Within the research paper, *Visual working memory performance in aphantasia*, an individual study was conducted looking into how visual working memory is impacted by those who identify with aphantasia (Jacobs et al., 2017). In "Learning with Aphantasia," an article posted on the Aphantasia Network website, pointed out learning through different toolsets and that there is no designed alternative strategy to aid those with aphantasia and the learning process ("Learning with Aphantasia," 2019). Pearson's article, *The human imagination: The cognitive neuroscience of visual mental imagery*, discusses using neuroscience to justify and analyze findings in aphantasia (Pearson, 2019). In 2015, research was conducted on people who felt they lacked an internal visual memory, and the researchers focused on identifying and defining the term congenital aphantasia (Zeman et al., 2015). After the first paper, *Lives without imagery – Congenital aphantasia*, the same authors from the previous article then followed up a year later, reflecting on congenital aphantasia and seeking to understand how it impacts lifestyles (Zeman et al., 2016).

Information Extraction tools. Research exploring tools that already interact with complex written systems was looked at in the form of information extraction tools programmed to aid initial search features.

Chen and Ho researched creating a helper tool that combines the use of text mining and reading assistance to provide a smoother searching experience within a specific scientific database (Chen & Ho, 2014). The article, *BioRAT: Extracting biological information from full-length papers*, discusses the usefulness of having a uniform format for research papers as well as proposes an information extraction tool that uses the standardized format to aid the searching process (Corney et al., 2004).

Website-based assistive extensions. Several different assistive tools in the form of website extensions were considered for how they integrate into a user's life and provide accessibility.

Cervone and Sorge looked into designing a mathematical web-based helper tool using personalization in accessibility features (Cervone & Sorge, 2019). Ok and Rao provided a list of helpful learning resources that augment the educational experience for students in a positive way (Ok & Rao, 2019). Pérez looked at a different way to interpret navigating through websites using only voice in the journal article, *Handsfree for web* (Pérez, 2019).

Visual Cues and Memory Triggers. The following papers look at understanding both long-term and visual working memory recognition tactics, such as visual cues, to support association-building and learning.

Mayer and Moreno explain ways to reduce cognitive load in multimedia learning by introducing a theory: cognitive theory of multimedia learning (Mayer & Moreno, 2003). In *Attention capture by episodic long-term memory*, the research team explored contextual cueing as a means to trigger the episodic and long-term memory (Nickel et al., 2020). Sadoski and Paivio discuss dual coding theory within the context of literacy and break down what that means for comprehension and memory (Sadoski & Paivio, 2013). Shimi and Logie looked at how visual cues when used in feature combinations, work together to build long-term memory associations (Shimi & Logie, 2018). Sutterer and Awh investigated how visual cues increase the probability of success in recognition, not necessarily the quality, and remembering something from long-term memory (Sutterer & Awh, 2015). Vierck and Miller in their paper, *Direct selection by color for visual encoding*, discuss the nature of visual cues and what the mind does when seeing one, as well as what visual cues are strongest (Vierck & Miller, 2005).

Table Bibliography

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Website Based Assistive Extensions	
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2.4   Definition of Terms

Listed here are keywords used throughout the document as it pertains to this investigation.

Accessible Format: A way of presenting information that originally is printed, written, or visual in multiple forms in order to not discriminate against those with impairments.

Aphantasia: Also known as "congenital aphantasia," is used for individuals who are unable to voluntarily visualize things within their mind's eye.

Cognitive Process: The performance of a mental activity that requires the individual to use mental contents, such as thinking or remembering.

Complex Task: A function that requires a certain degree of skill or ability of interrelated and interdependent components.

Data Extraction Tool: A tool or program that can read through raw text or data of information and extract, or compile, this information in one location for a purpose.

Dreaming: The act of seeing involuntary imagery as one sleeps.

Dyslexic Typeface: Dyslexia is a condition in which an individual struggles to comprehend or recognize written words. A dyslexic typeface is a special kind of typeface, or font, designed to aid these individuals so that they can read more coherently.

Episodic Memory: A form of long-term memory that relies heavily on the visualization of personal memories in an individual regarding a certain event or place.

Framework: A visual representation or process of an idea, theory, or body of literature using shapes, lines, and even color to portray information.

Future Event Prospection: The ability to look at events in the future and calculate their ability to happen and the outcomes of such.

Hyperphantasia: A term used to describe individuals with vivid or hyper-realistic voluntary imagery.

Involuntary Imagery: Refers to the inactive or subconscious state of using visual mental imagery.

Mind's Eye: When one closes their eyes, they are looking at their mind. The "Mind's Eye" is the ability to see things when in this space.

Note-taking Method: An experience unique to an individual on how they take notes (store information).

Multi-Sensory Loss: The loss of several different physiological senses, such as touch, sight, hearing, smell, taste, and sense of space, specifically as a mental trigger for memory.

Phantasia: Historically taken from the Greek term for imagination, phantasia is a term used for anyone who has the ability to see images and mental representations within their mind's eye.

Research Paper: A piece of academic writing containing research and other source material, usually within a standardized format.

Visual Mental Imagery: The presence of picture-like representations within a mind's eye.

Visualize: The ability to voluntarily summon picture-like representations within a mind's eye.

Voluntary Imagery: Refers to an active conscious state of using visual mental imagery.

Web Extension: A scripted code with a user interface that an individual can interact with as it reads the information on a webpage and then interacts with it based on what it was planned to do.

2.5 Assumptions and Limitations

Assumptions

In this investigation, I assume three main things about machine learning upon which the design interventions depend. One, that machine learning is capable of managing and conducting this investigation. Two, that the machine learning algorithm can realistically be engineered and programmed to follow through on explorations. Three, that machine learning can embed in the extension easily without draining resources from the CPU. The investigation is running on the idea that there are not any privacy concerns between the program and the user's data.

Limitations

The purpose of this investigation is not to take away from how one might process materials with aphantasia, but rather provide tools to aid their processes and make a complex task, much easier. It is important to note that while the investigation focuses on people who have aphantasia, the field of study is still growing, and as such so is the research. This investigation is based on the current understanding of aphantasia, which is subject to change.

2.6   Precedents

This investigation poses interesting questions about what kind of precedents exist in related problem spaces. Looking at how information is portrayed in a digital format and how much that impacts the user's ability to build connections within the text is key to understanding how to build a system that can address aphantasia. A further look into helper tools that can aid people in making digital formats easier to comprehend and interact with is important when addressing accessibility design.

Individual assessments:

[1] Mercury Reader (see Figure 2.6.1): a Google Chrome extension that reads the data of a website and provides access to the main content without the distraction of navigation bars, ads, etc. It also synthesizes the data to a set width that makes the words easier to read.

[2] Fika - Reader Mode (see Figure 2.6.2): a Google Chrome extension that offers a clear reading mode as well as a few adjustable traits like the change to typeface size and backgrounds. It also takes key points and builds a table of contents to the side of the reading mode.

[3] Wikiwand (see Figure 2.6.3): a Google Chrome extension that reads Wikipedia pages and reorders the information on the page to maximize readability within its users. It adds a table of contents to jump around in the article on Wikipedia, as well as formats the pictures into a gallery mode and makes the location more fit within the context of the page.

[4] Reader Mode (see Figure 2.6.4): A Google Chrome extension that reads the data of a website and compiles it into another "read" mode where the user does not have to deal with excessive ads or navigation distracting from the experience. This specific extension allows the user to create style sheets for a preferred way of website browsing, as well as access to features like dyslexia fonts and text to speech reading.

[5] Weava Highlighter (see Figure 2.6.5): This Google Chrome extension allows users to collect key data points they want from a reading by color-coding highlighted text. The highlighted text is then trans-

ferred to a "research folder" in the extension where it saves the website and the content highlighted. This makes sourcing information and drawing out key points easier.

[6] Hypothes.is (see Figure 2.6.6): A flexible browser extension that allows users to highlight, annotate, and collaborate within selected texts and notes. It has a tag feature that allows users to tag the content they find and want to store for later under a key term so that they can later look through everything they filed under that tag.

[7] Immersive Reader [Microsoft Learning Tools] (see Figure 2.6.7): A learning tool specifically designed to help people with learning disabilities, this plug-in is only available to Microsoft OneNote usage, but it breaks down words and highlights as the user reads along to emphasize the content they are reading rather than decoding what else is happening.

[8] Sprint Reader (see Figure 2.6.8): A Google Chrome extension that is highly configurable and takes selected text passages and converts them into sprint exercise reading which makes the reading process faster while also allowing users to comprehend what they are reading. Sprint reading is a type of reading where only one word is available at a time and one letter is highlighted so that the reader centers their eye there and can then read the words as they flash on the screen quickly.

These precedents, taken together, suggest the following conclusions.

- There exists a congruency in websites where many inhibit readability or express excessive information in one location.

- All of the featured are extensions or plugins that augment the experience of a web-based site, as opposed to a platform or application that is accessed on the desktop.

- There are many ways an extension can approach synthesizing data down to enhance readability.

- Aside from taking the raw content and showing it in a new way, there is not a synthesis to break down information.
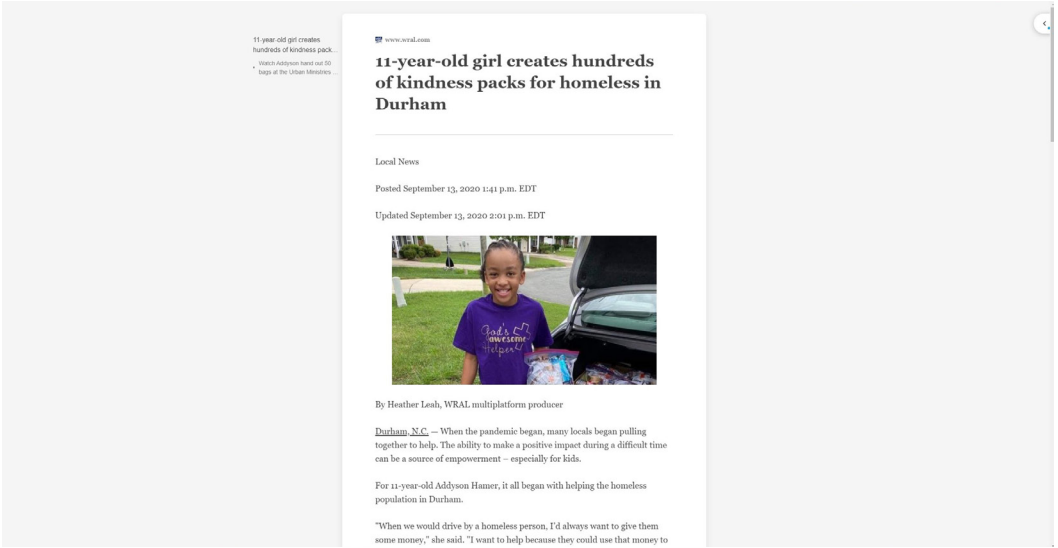
Figure 2.6.1. Mercury Reader.

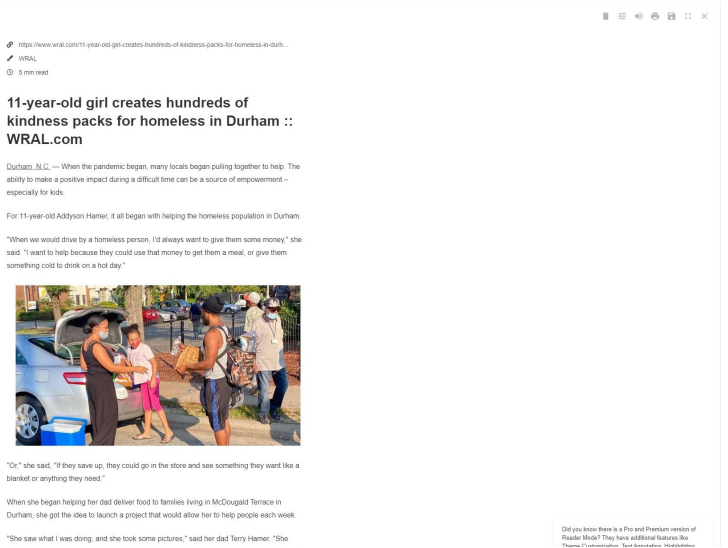*Figure 2.6.2. Fika - Reader Mode.*

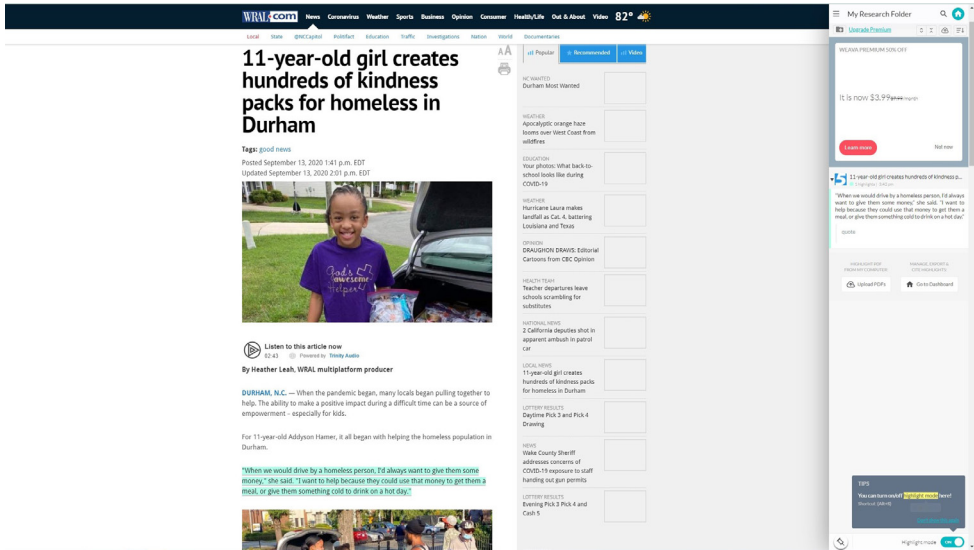*Figure 2.6.3. Wikiwand.*

Figure 2.6.4. Reader Mode.

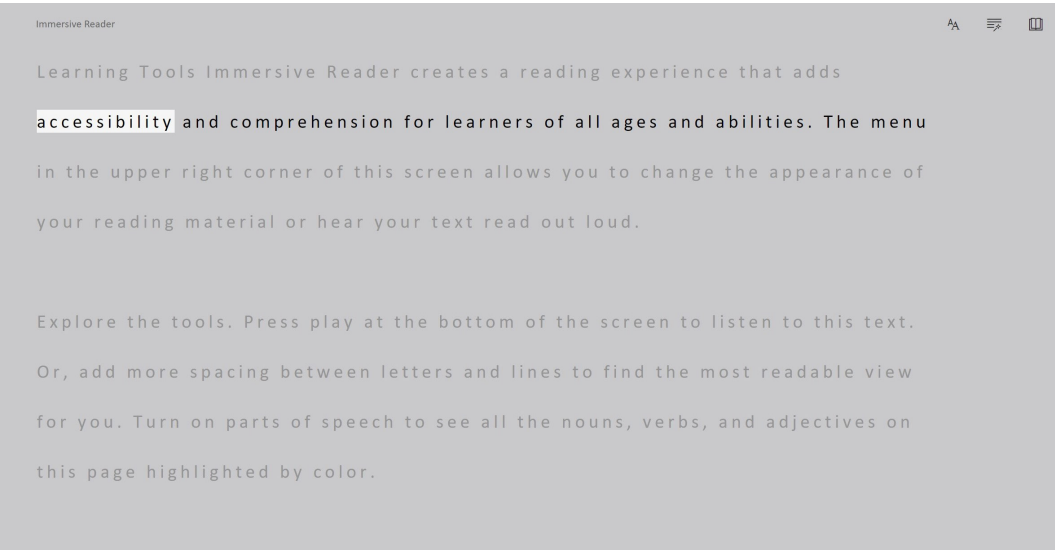*Figure 2.6.5. Weava Highlighter.*

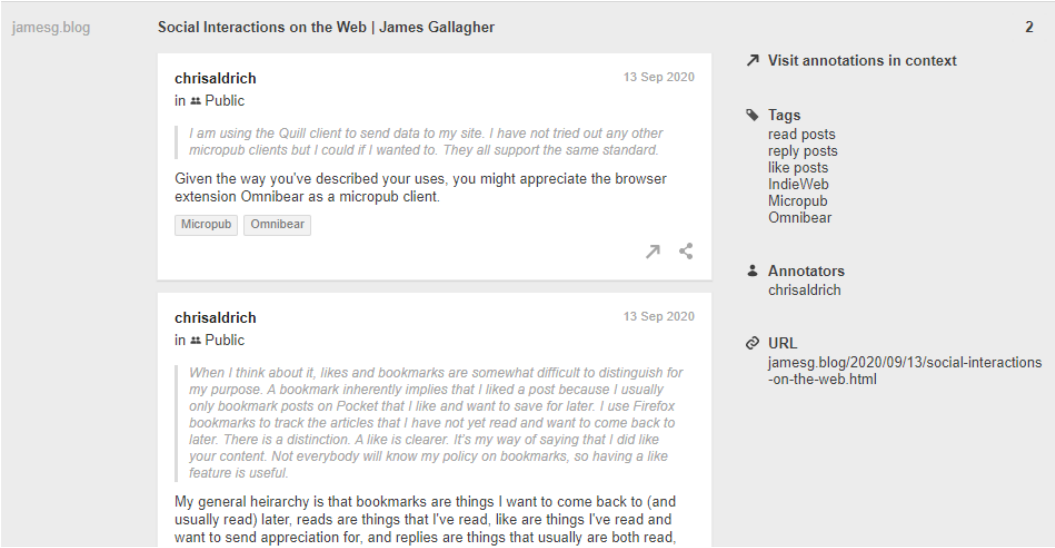*Figure 2.6.6. Hypothes.is.*

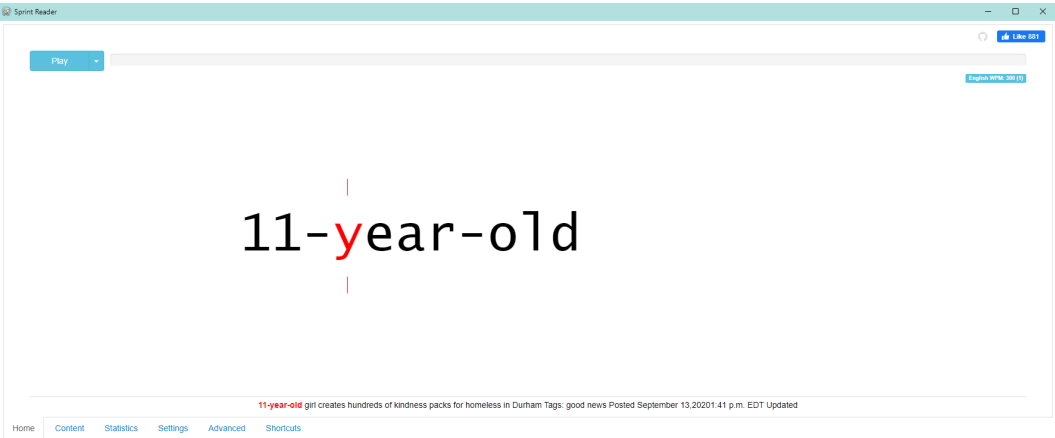*Figure 2.6.7. Immersive Reader [Microsoft]*

Figure 2.6.8. Sprint Reader.

3
INVESTIGATION PLAN

3.1.   Conceptual Framework

The framework for this investigation (see Figure 3.1.1) is based on (a) Paivio's depiction of Dual Coding Theory in Sadoski and Paivio's Imagery and Text reading and (b) Mayer and Moreno's framework for Cognitive Theory of Multimedia Learning.

Dual Coding Theory (see Figure 3.1.2). Sadoski and Paivio discussed Dual Coding Theory (DCT) in the context of literacy in their book *Imagery and Text* (Sadoski & Paivio, 2013). This framework discusses the difference between verbal stimuli and nonverbal stimuli and how that explains cognitively to elicit a response or store as new knowledge. Verbal stimuli are not limited to spoken verbal, but rather a word or letter standing for something else. On the other hand, nonverbal stimuli are the association for the meaning itself. For example, the word "cow" would be a verbal stimulus via logogens while the image of a cow would be a nonverbal stimulus via imagens. These stimuli are then sorted through our senses into representational connections that activate either a verbal or nonverbal system. Within this process, associations are referenced to draw referential connections, or where one system activates the other and this leads to a response. All of the original information from the theory is kept for the scope of this investigation, however, further providing clarity to the theory is found when combined with the cognitive theory of multimedia learning.

Cognitive Theory of Multimedia Learning (see Figure 3.1.3). Mayer and Moreno took inspiration from the DCT and further applied that into the context of learning via multimedia (Mayer & Moreno, 2003). Their framework divided into distinct sections via color to show what cognitive processes are used throughout this process. This color-coding was kept in the integration with DCT as well as giving meaning to what the mind does with the information, such as selecting what to investigate further and organizing the information. The scope of this investigation aims to use stimuli to build associations and then add that to existing knowledge, and have that knowledge give back when needed.
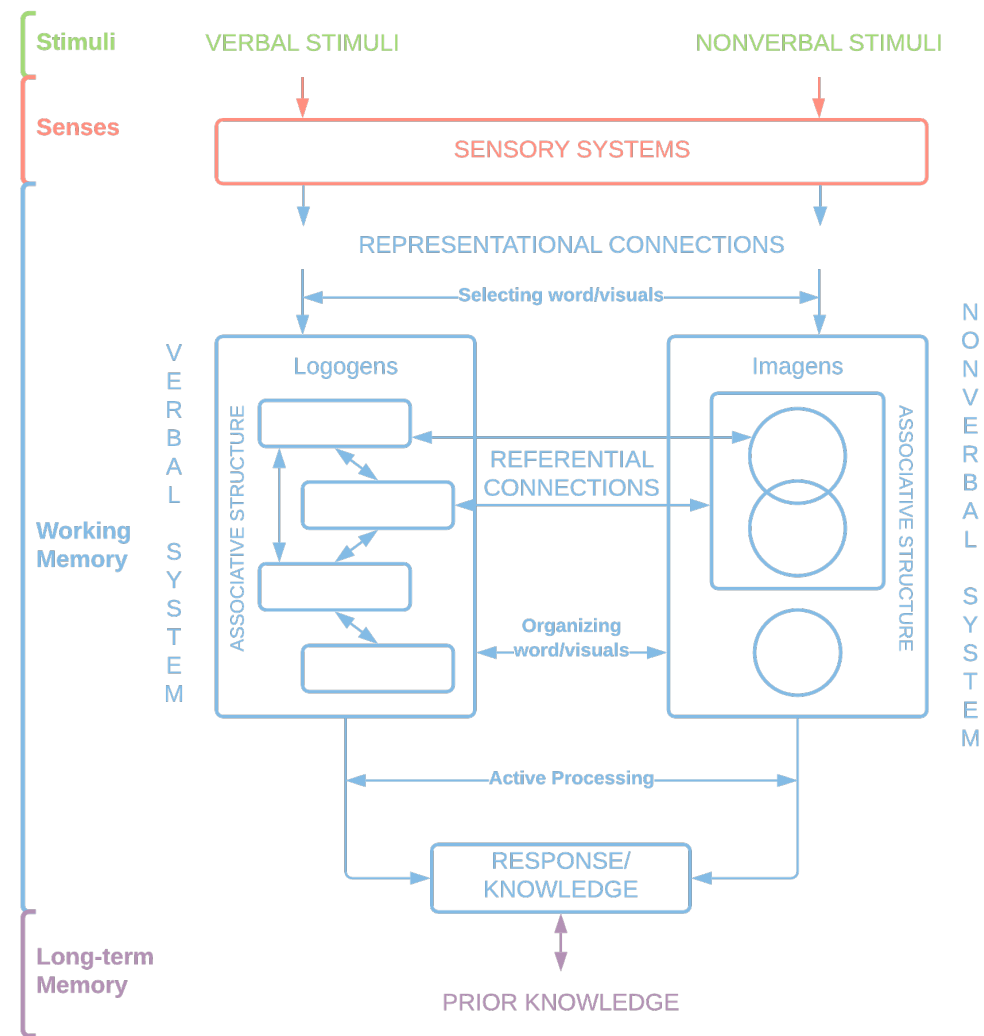
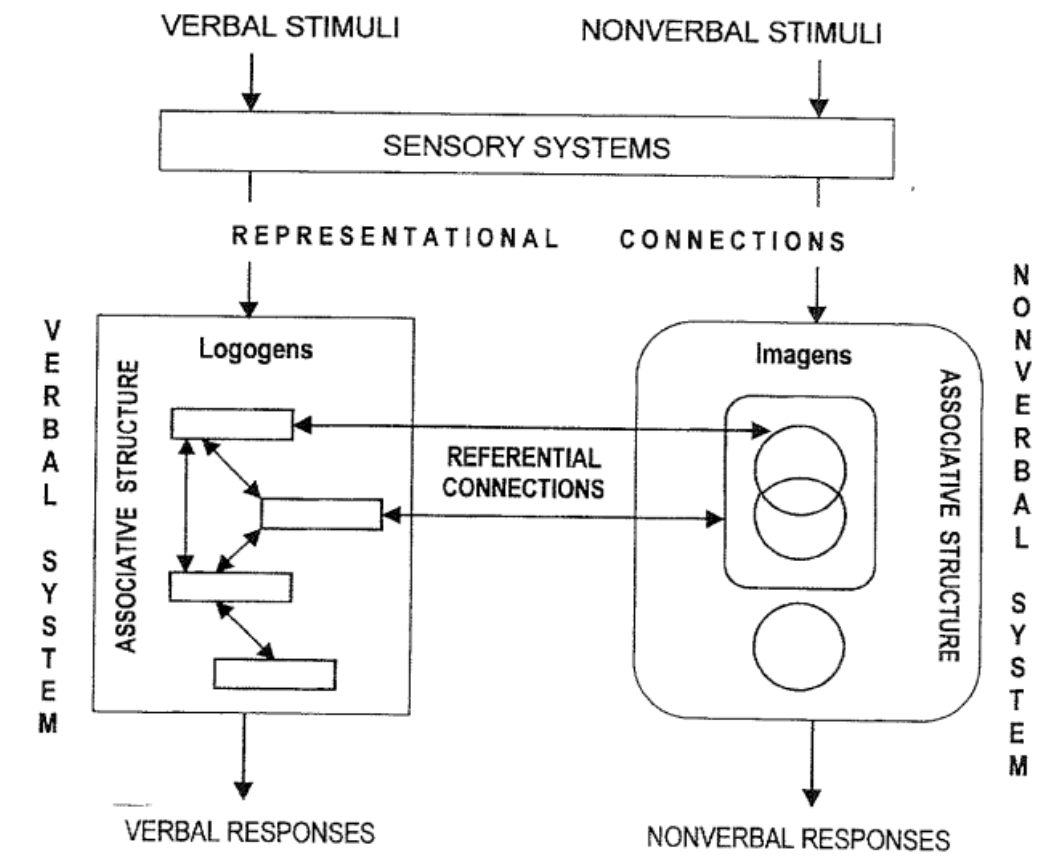Figure 3.1.1. Conceptual Framework for Understanding Memory Performance.

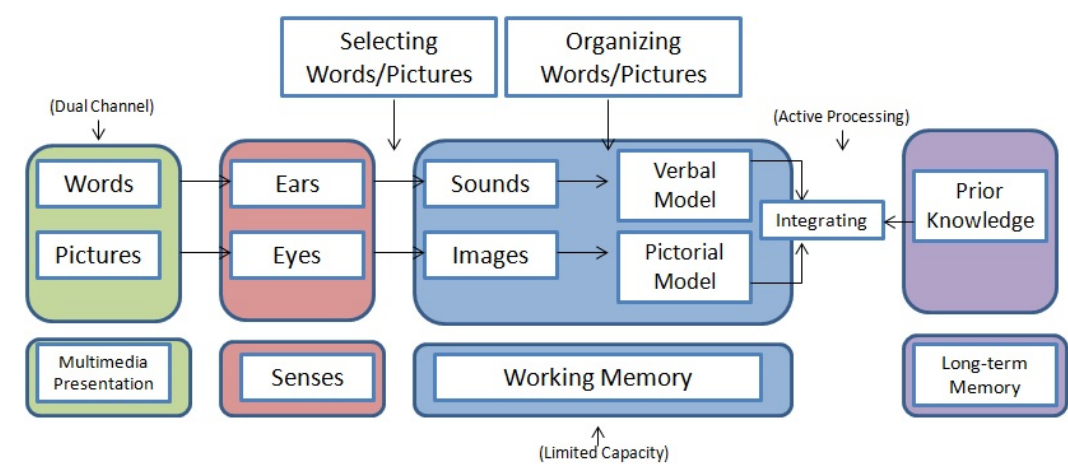Figure 3.1.2. Dual Coding Theory.

Figure 3.1.3. Cognitive Theory of Multimedia Learning.

3.2.   Research Questions

The following questions frame the individual studies within the larger investigation scope.

Research Question:

How can the use of recognition in association-building within a web extension make digital research papers more comprehensible for undergraduate students with aphantasia to improve memory performance?

Subquestions:

1. How can the design of visual cues and hover states foster relationship-building via associations in order to improve memory performance?

2. How can the restructuring of information in the form of framework building be used to put information into perspective using visual cues to establish a connection in the user?

3. How can the extension integrate a user's note-taking method into the process of reordering information in the form of a framework to establish collaboration between user and technology?

4. How can the integrations of hover traits, framework building, and note-taking work together to foster association-building in aphantasics while working with research papers?

3.3.   Investigation Model

The two models depicted in Figures 3.3.1 and 3.3.2 show how the studies will function as well as where each investigation will roughly take place. Figure 3.3.1 expresses the complexity of a task for the machine learning extension. The questions posited in this figure simplify the main objective of the subquestion as well as use a gradient to determine the hierarchical structure for which the subquestions can be understood. Figure 3.3.2 shows the context of the research investigations and where each subquestion will interact with a research paper.
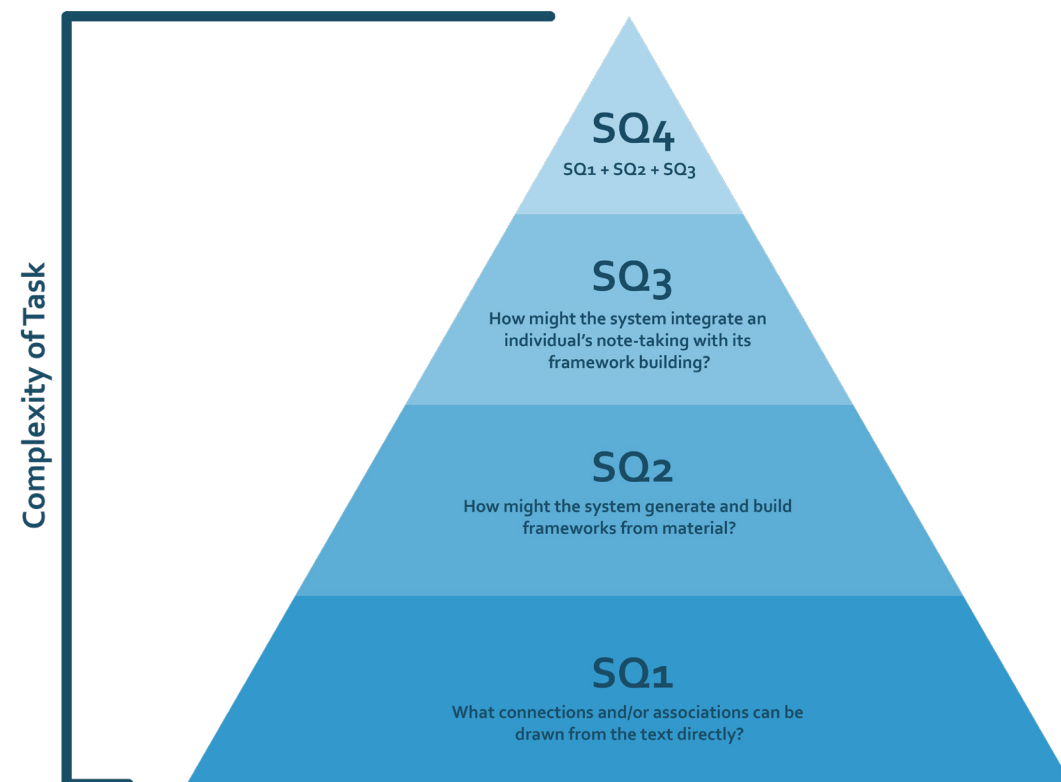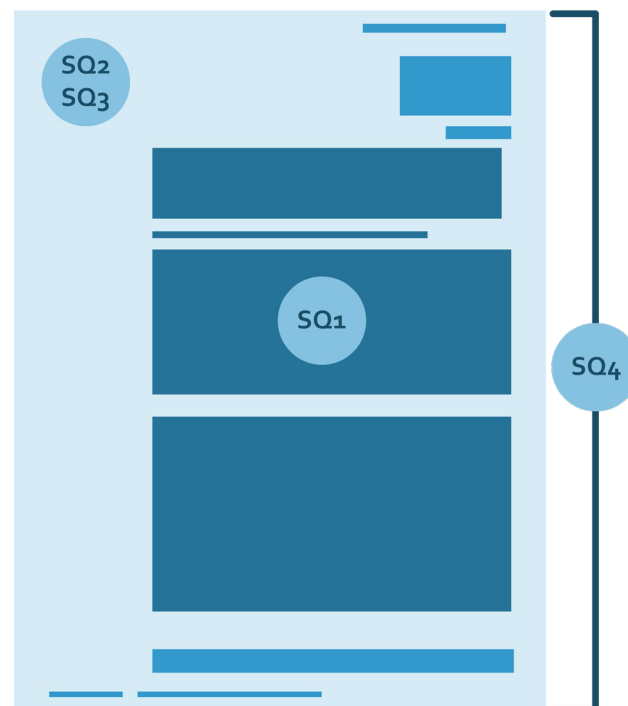
Figure 3.3.1. Hierarchy of Subquestions.

Complexity of Task

SQ4
SQ1 + SQ2 + SQ3

SQ3
How might the system integrate an
individual's note-taking with its
framework building?

SQ2
How might the system generate and build
frameworks from material?

SQ1
What connections and/or associations can be
drawn from the text directly?

SQ2
SQ3

SQ1

SQ4

Figure 3.3.2. Where the Subquestions Live.

3.4.   Scenario

Olivia is a second-year biology undergraduate student at North Carolina State University with self-diagnosed aphantasia who has figured out a routine for learning and studying. Typically, she is more hands-on with learning and finds that mapping content graphically is useful when digesting large volumes of text because she is unable to draw it out in her mind. Most of her classes offer a healthy blend of readings and interactivity that requires her to build associations and makes things easier to process and store later. Even when reading a book, the tactile touch of the book, its natural scent, being able to highlight, note-take in margins, and weight is something that helps in remembering information. She does not mind picking texts apart; she finds that seeing the ideas represented visually makes her mental associations click more into place and she often manifests these through frameworks. When faced with larger classes that can be impersonal, she reaches out to classmates and builds out their ideas via mind-maps and other visualization tools to make sure everyone is on the same page.

Unfortunately, a pandemic has hit and everyone is at home and online, so what previously planned activities are being displaced in favor of an adaptation to literature-focused learning. She is now told to make sense of readings, via websites and PDFs, before "coming" to class, and class has converted more to an open discussion rather than an exploration via activity. This is asking her to be more self-taught rather than the mediated guidance she had received previously with classes. While she can read the content asked of her, she is having a harder time building associations to remember the readings and contribute to discussions. Her grades on quizzes and participation begin to slip because her notes are not representative of anything, either visually or associatively.

This scenario focuses on a browser extension that reconfigures data from a source and use machine learning to make sense of the text and work together with the user to create lasting notes via her personal note-taking method, framework building.

Olivia finds through several YouTube videos of recommended extensions that one has an emphasis on aphantasics. She installs the extension and sets it up in her browser bar before navigating to a research article on topic relating to her litreature review. Initially, the information is lacking in figures, and the wall of the text becomes overwhelming. So she clicks the icon representing the extension and her view changes. The margins become larger as the text fits a more digestible format. In the margins is a toolkit. The limited machine learning software in the extension has extracted data and attempted to parse together common themes from the reading to create a framework map. The use of color and shape to highlight certain aspects of the material makes it easier for Olivia to digest the information while reading through the document and therefore create meaningful associations based on the framework mapping.

4

STUDIES

4.1. Drawing Connections Within Text

Initial expectations for the first study's investigation were to look at how a user may build associations from the text directly. Applications that can happen with text directly on a digital surface are color, spatial, and shape cues. Color and spatial cues are the strongest visual indicators for someone with aphantasia to trigger a quick memory response. This investigation is broken down into several mini explorations of how text can be spatially rearranged or presented in a way that will enable easier use and recognition.

The execution of the study was presented in three main stages centered around ideation, iteration, and refinement. Due to the nature of the phases, there are various states of fidelity in the following visual explorations.

Research Paper Visualizations

A question that came about while exploring information portrayal was how one can indicate visually that there are connections to be drawn within the text that cannot be distinctly seen from the one page. First, a break up of what sections exist in a research paper was explored, as found in Figure 4.1.1. Following a greater understanding of sections, visual iterations were explored looking at how a paper could be represented to a user. Figure 4.1.2. looked at a variety of visualizations that could take place in the margin section. If an interaction was determined to take place, a visual menu would show where else the indicator can be found. The point for these explorations was to look at how different forms of visual representation could change a user's interactions and perceptions of a paper.

Visualizations can help users see content forthright that would otherwise be hidden by the use of scrolling. It is possible that seeing these visual relationships may aid in a unique understanding of an academic paper and with the aid of further explorations in hover state usage, allow for transparency.

Reflow of Text

Thinking about precedent research, there was an interest in exploring a reflow of a research paper's text into a more digestible format that might allow for easier reading and accessible features. Margins and sizing were the most important aspects of this exploration as seen in Figure 4.1.3. How might elements (different bodies of text) relate to one another and still provide a story? Paper margins themselves are rather large to accommodate printers, so working in a purely digital space, text can flow differently and allow for larger margin space to work with. Whether that space should be much tighter than the paper variant, or just slightly smaller was left to explore.

The point of this exploration was not to figure out technical logistics, but rather, to garner a general feel for how a paper may begin, how hierarchy persists in this new format, and should there be padding

around the text before it hits the margin. After establishing an overall feel, a toggle-able accessibility bar was designed featuring three major themes: text size, typeface style, and theme.

System Versus User Association Builder

When working with a digital system, there are two distinct ways that one can visually see the information: 1) either more organically as if another human had created the cues 2) more static as though the system had calibrated the cues. Questions to explore were: What might be a difference in the visual design of in-text interactions prompt from a user? What might prompt a user to find the system friendly, engaging, and easy to use between the two polarities of system-generated versus hand-drawn visual cues? What kinds of visual cues can exist within the text without disrupting the information? The aim of these questions was to explore possibilities between system and user content and what would help create associations to commit to memory.

Hand-Drawn Versus System-Generated Cues

Figure 4.1.4. features the difference between hand-drawn and system-generated visual cues. There is a certain organic feel with the natural waver of a person's hand when drawing marks, that may, in execution, provide a sense of familiarity with the user. On the other hand, the stable and systematic approach to visuals that the computer could create is very clear-cut and to the point. The point of the exploration was to see how text changes with the interaction between the system and hand-drawn cues between three major note-taking associated cues: underline, boxed, and highlight.

Full User Autonomy

After establishing what association cues are most often used with note-taking, this exploration focused on taking the hand-drawn effect and applying that to interactions a user could have within the text. This exploration, as seen in Figure 4.1.5. has three major parts. One where a user enacts one of each note-taking visual cues to get more information out of the paper they are looking at. This exploration examines a modular card system to the side where a user can refer to the information easily with a glance. The benefits of this card system give the user the ability to control what they want to interact with, and knowing consistently how that information will portray itself.

Full System Assist

Figures 4.1.6, 4.1.7., and 4.1.8., explore a situation in which machine learning is parsing through the text of the research paper and determining what more the user might want to know. The features this system provides are similar to the example in the full user autonomy exploration (found on pages 40, 46. See Figure 4.1.5.) to allow for cross-reference on what might be more useful to an individual with

aphantasia. Unlike a modular card system, this approach explores hover states where the information is only temporarily shown when the mouse is positioned directly over the text.

Reflection

The point of these devices, as shown through visual explorations, is to aid individuals who have aphantasia to easily draw associations that would otherwise get lost when reading through heavily filtered academic texts. Since aphantasics rely mostly on their ability to associatively think and process the world around them, having a consistent visual format that is easy to use and understand was important to this study. From there, it was about exploring where changes could be made to encourage a more productive and accessible experience. There are many experiences that could be tweaked that were acknowledged throughout the process such as time constraints placed on investigation. Other experiences worth looking at include exploring more in-text interactions like visibility, pushing, or replacing directly. Other areas of interest included user interface variability and exploring how a user with aphantasia might select what they want to focus on when using the web extension.

Study one is the foundation from which further studies build on and it was important to understand the fundamentals of format and visualization to proceed with the later studies.

	Always Present	Sometimes Present	Text Heavy	Image Heavy
Title	■			
Abstract	■			
Keywords		■		
Introduction	■		■	
Limitations		■	■	
Methods	■			■
Literature Review		■	■	

Figure 4.1.1. Sections of a Research Paper. Featured is a table with common significant sections of research papers divided into how often they are present and whether they are text or image-heavy.
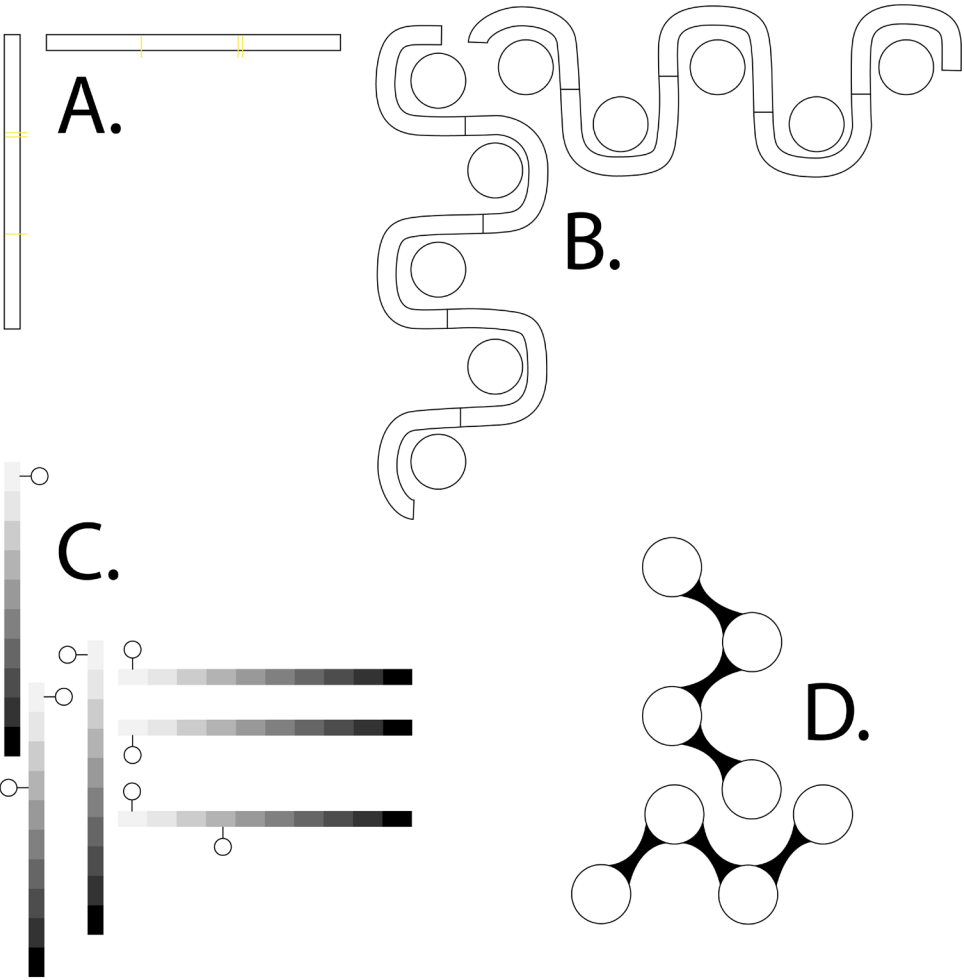

Figure 4.1.2. Paper Overview Visualizations. A. Expresses a minimal bar visualization where the only indicator would be the marking of where else the visual cue can be in the paper and then a user could click the marking and jump to that section of the paper. B. Represents a more visual approach to showing a paper where sections are broken up by sections and the length corresponds to the length of the paper. Each circle represents an icon placeholder representative of the section of the paper it is tied to. Again, a visual cue indicator on one page would show other variants of it and the actions would mimic Figure A. C. A little more traditional, this visualization features section bars equal in length to what they correspond to, as well as when hovered on, an icon indicator of what that section is. D. A more experimental approach features a more modular design with an emphasis on the section indicators. Each linking section would have a color unique to their section and a visual cue and its variants could be represented in the small space.
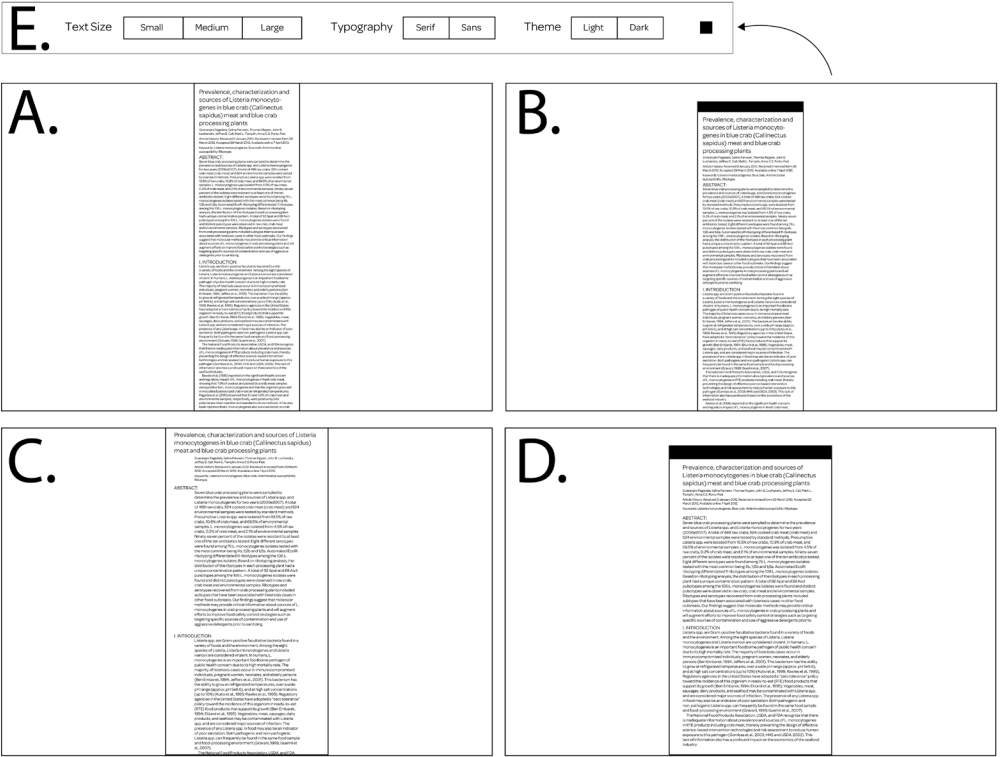
Figure 4.1.3. Reflow of Text. A. Having the text within a much tighter margin means having fewer words per line, allowing a user to quickly read through the information. This also allows for more space in the margins that the framework builder and page visualizers can work within. B. Unlike the first example, this reflow visually keeps the page motif by having a margin at the top (only for the start of the document), and then padding which allows for a toggle-able settings bar featured in E. C. Looks at slightly smaller margins than the standard PDF file but still allows for more room. The text is directly there with no visual motif and the user can just scroll through. However, to exemplify paper sections, large padding is used within the text to keep words per line down. D. Keeping with the start of a page motif and the accessibility toolbar, this example highlights larger margins but less intrusive padding, allowing for a smoother reading. E. A toggle-able toolbar that allows for the user to customize their text to their liking featuring major highlights such as text size, typography type, and theme colors.
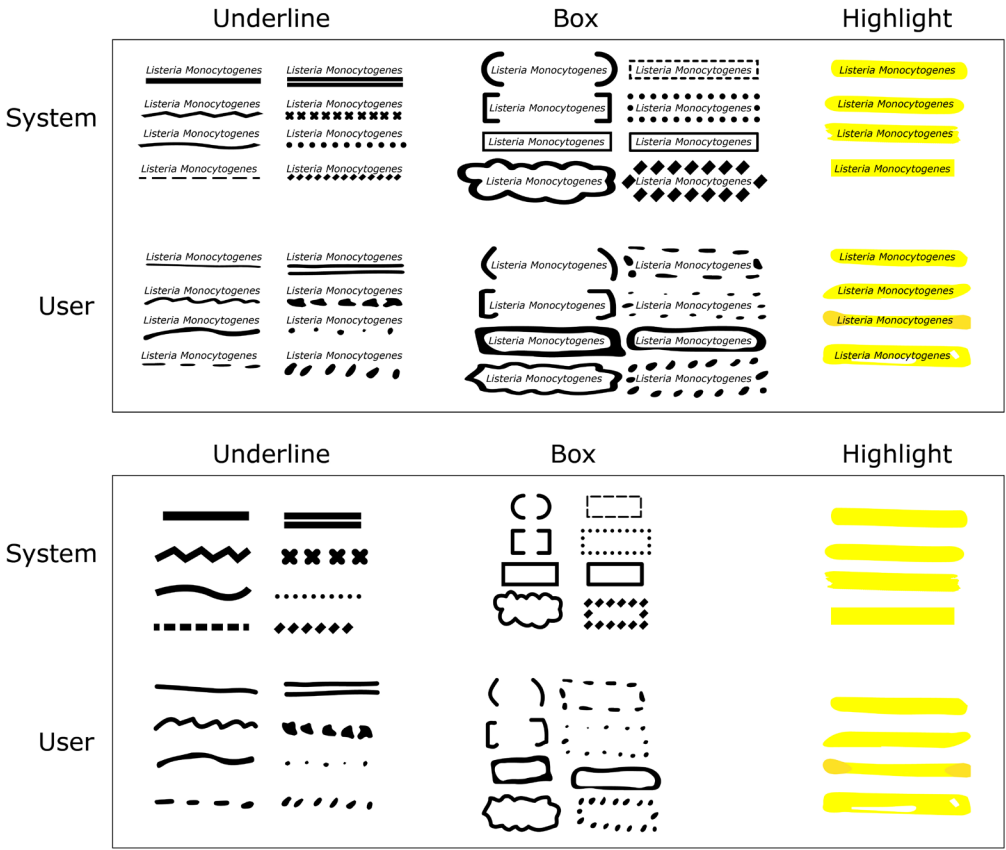
Figure 4.1.4. Visual Cues Within Text. Featured are two tables, both expressing how a system and a user would generate underlines, boxes, and highlights. The first table features how those markers would interact with the text itself while the second is just the visual markings themselves.
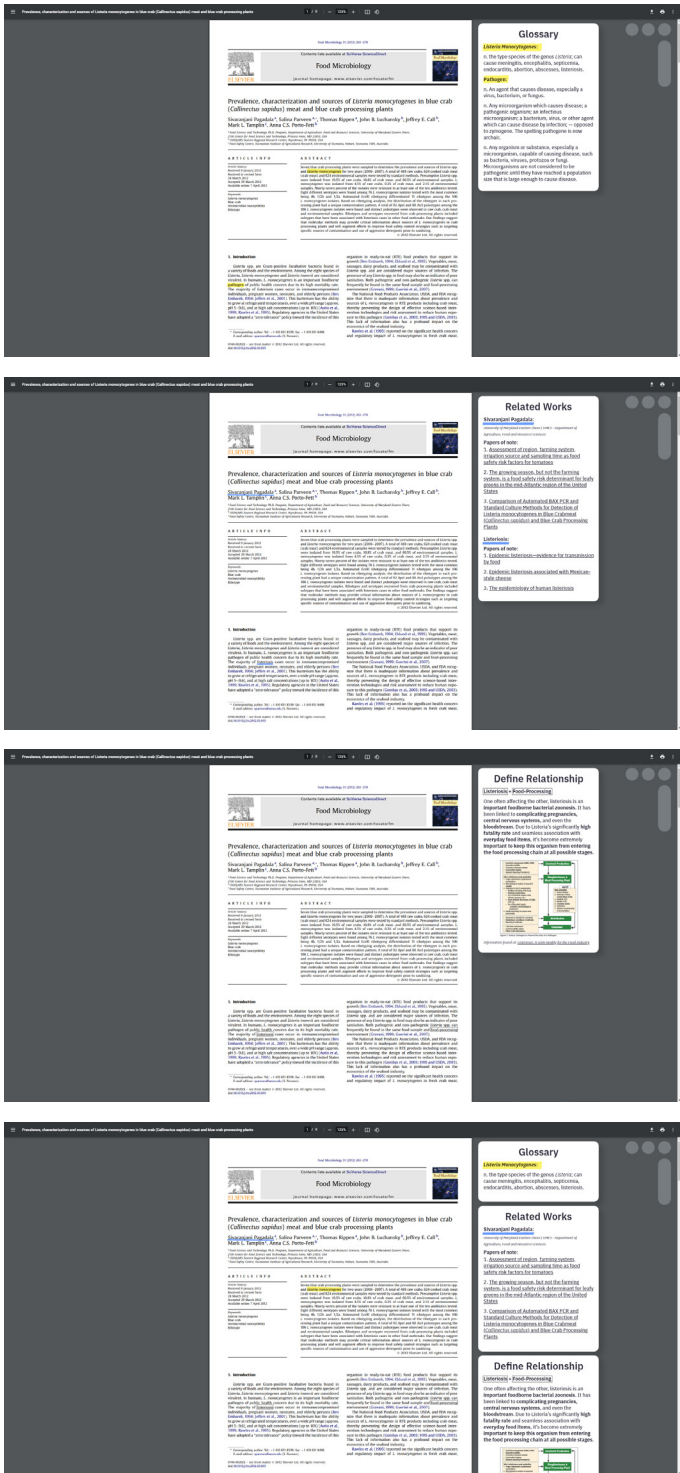
Figure 4.1.5. User Determined Cues. The first visual expresses a system in which the user determines what it is they want defined and then highlights and builds a glossary card. The second example shows the user using an underline tool where they want to see what other works are featured by the highlighted term or name. The third visual uses a boxing visual cue to prompt the user to select two options and then a "define relationship" card will appear, exploring how the two terms relate to each other. The last representation looks at how this card system would work in tandem with one another.
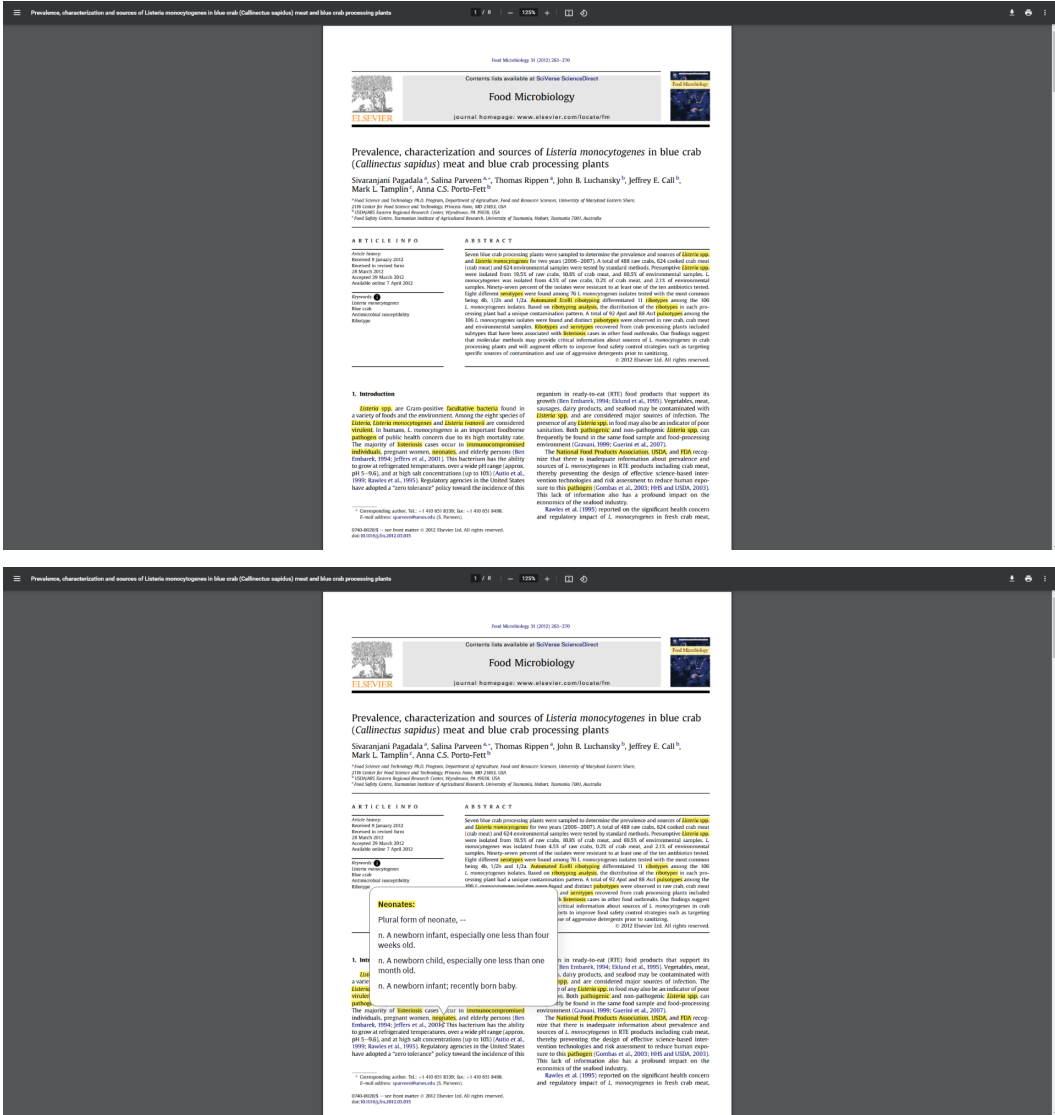
Figure 4.1.6. System Determined Cues - Highlights. Examples show the system determining more difficult words that the user may want help with understanding and then when a user hovers over the information, an info card pops up with a definition.

Figure 4.1.7. System Determined Cues - Underline. These examples feature the system underlining individual names and prompts the user to hover, showing a little description of who the person is and what their most popular papers of note are.

Figure 4.1.8. System Determined Cues - Web. These images show an icon next to the keyword section that when selected opens up a pop-up window with a word web. The circles are used to show direct keywords as decided by the paper and the rectangles are keywords the system found that relate from within the abstract. If the user clicks on any of these, another pop-up window appears where a user can look at top papers of note for the selected term.

4.2. Data into Frameworks

Study two delved into the logistical side of how the framework building system functions, what information is it pulling from, what can it do on its own, and how does it reveal itself to a user? This part of the system is to coexist with what was foundationally established in study one, and the actual interfacing and user input is saved for study three.

Understanding Research Paper Formats

While the focus of this study is to look at a system generating frameworks from a reading, it is important first to determine and sort what kind of papers exist that this system could be working with. Mapping out how these formats relate to one another can be found in Figure 4.2.1. The associated objective of the paper is found in the table of Figure 4.2.2. Both figures present a lucid understanding of what formats the system will be searching for, sorting for, and working with.

Developing Framework Models to Use

Establishing what a framework is and what kinds the system will be interfacing with is important in understanding the fundamentals of a framework building web extension. This exploration, as found in Figure 4.2.3., looked at sorting examples of frameworks into three main buckets: time based, comparative, and structural. After determining buckets, several research papers were examined to see what kinds of theoretical and conceptual frameworks (and models) exist in papers and converting them into simple and easy-to-understand forms. These examples will function as a preset mode from which the system will be starting from. After establishing what kinds of frameworks the system will be working with, it was time to look at figuring out what bucket is typically found with what kind of paper, as seen in Figure 4.2.4.

Framework Appearance to User

The aims of this exploration were to look at different ways the system could portray the framework to a user. Examples feature a range of complexities found in Figures 4.2.5, 4.2.6., and 4.2.7. When looking at these examples, four main visual ideas were discussed with one being the control or static. The goal was to look at different ways emphasis, movement, and time-based framework appearance might affect the user's experience. Depending on the complexity of the framework, different forms of visual cue were used to bring attention to the example being tested. Time-based was further split up into a mini-in-

vestigation that looked at the difference of real-world time passing versus reading progress in paper time passing, as found in Figure 4.2.8.

Framework Structure to User

When looking at this investigation, the main question focused on how the information in the framework is actually portrayed. Does the system prompt the user to interact with it to build the framework, or does it fill on its own? Figure 4.2.9. features a visualization of the system automating the framework and how it would build the framework for the paper it is looking at. The system's automation is determined to read through the information and glean enough information to quiz the user as shown in Figure 4.2.10. Another method of looking at how the system may portray a framework to a user is through prompting the user to search through the paper and find keywords or phrases that the system thinks are useful as shown in Figure 4.2.11. Giving the user more freedom in the generic experience of the framework builder, a user can either move keywords that the system has selected, shown in Figure 4.2.12., or they may create their own modules to move around and place on the default visualization of a framework, as it appears in Figure 4.2.13.

Reflection

This investigation focused heavily on the logistics of how the framework would function within the extension. Originally its focus was on figuring out what frameworks the system would come up with, but as time progressed, understanding what academic papers the system could read and how it went about displaying that information to a user became important.

Since the aim of this extension is centered around aiding users with aphantasia while actively reading a paper, some examples from which the framework portrays itself to the user are stronger than the others. For example, in Figures 4.2.5, 4.2.6, and 4.2.7, establishing a sense of movement may be distracting to a user trying to commit a certain visual to memory, so a static form would help establish that memory and later allow for memory retention. The framework's information portrayal could be stronger to an aphantasic by having either a static example, building the framework via quiz, or allowing the user to create their own modules and move them into designated places.
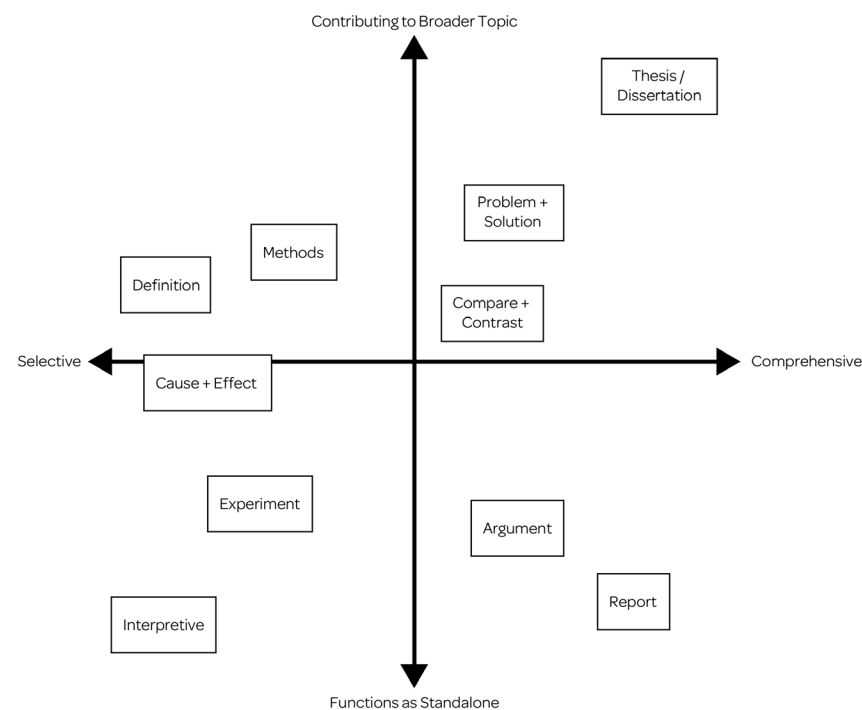
Figure 4.2.1. Research Paper Variations. This Figure depicts a quadrant framework exploring where different types of research papers exist within an academic space. The left alignment means that the papers are more selective, focusing more on their point than the other literature that exists. The right alignment looks at comprehensive research papers where many different sources are cited throughout to support the writing. The top alignment means that the paper is contributing, usually as a goal, to the larger body of literature in the given topic it is discussing. The bottom alignment looks at a paper that can function as standalone, meaning it is more individualistic in its approach.

Analytical	• Poses a question
	• Focus on findings + conclusions
	• Personal conclusion
Argumentative	• A controversial idea presented with two sides
	• Cited findings and arguments of both sides
	• Favored one side
Cause + Effect	• Analyzed two different viewpoints
	• Compared and contrasted both sides
Compare + Contrast	• Looks at probable or expected results from a specific action
	• Answers questions like "why?" and "what?"
	• Explains findings or study
Definition	• Describes facts or objective argument with no opinion
	• Include facts from a variety of sources yet leave unanalyzed
Experimental	• Describes a specific experiment in detail
Interpretive	• Looks at a specific case study
	• The approach is done via an established theoretical framework
	• Uses valid supporting data for main point and conclusion
Method	• Defining and describing a method of choice
	• Cites examples of use
	• About understanding method-use in studies
Problem + Solution	• Problem is described
	• A solution is proposed
	• Solution is defended
Report	• Compiles a bunch of literature on a particular topic
	• Sums the findings

Figure 4.2.2. Breakdown of Research Paper Variations. This table looks at various research paper types that exist and breaks down what the goals of the paper are.

Time Based

Kanban

Gantt

Timeline

Process Diagram

Comparative

Venn Diagram

Quadrant

Structure

Flow Chart

Pyramid

Funnel

Cycle

Target

Hub and Spoke
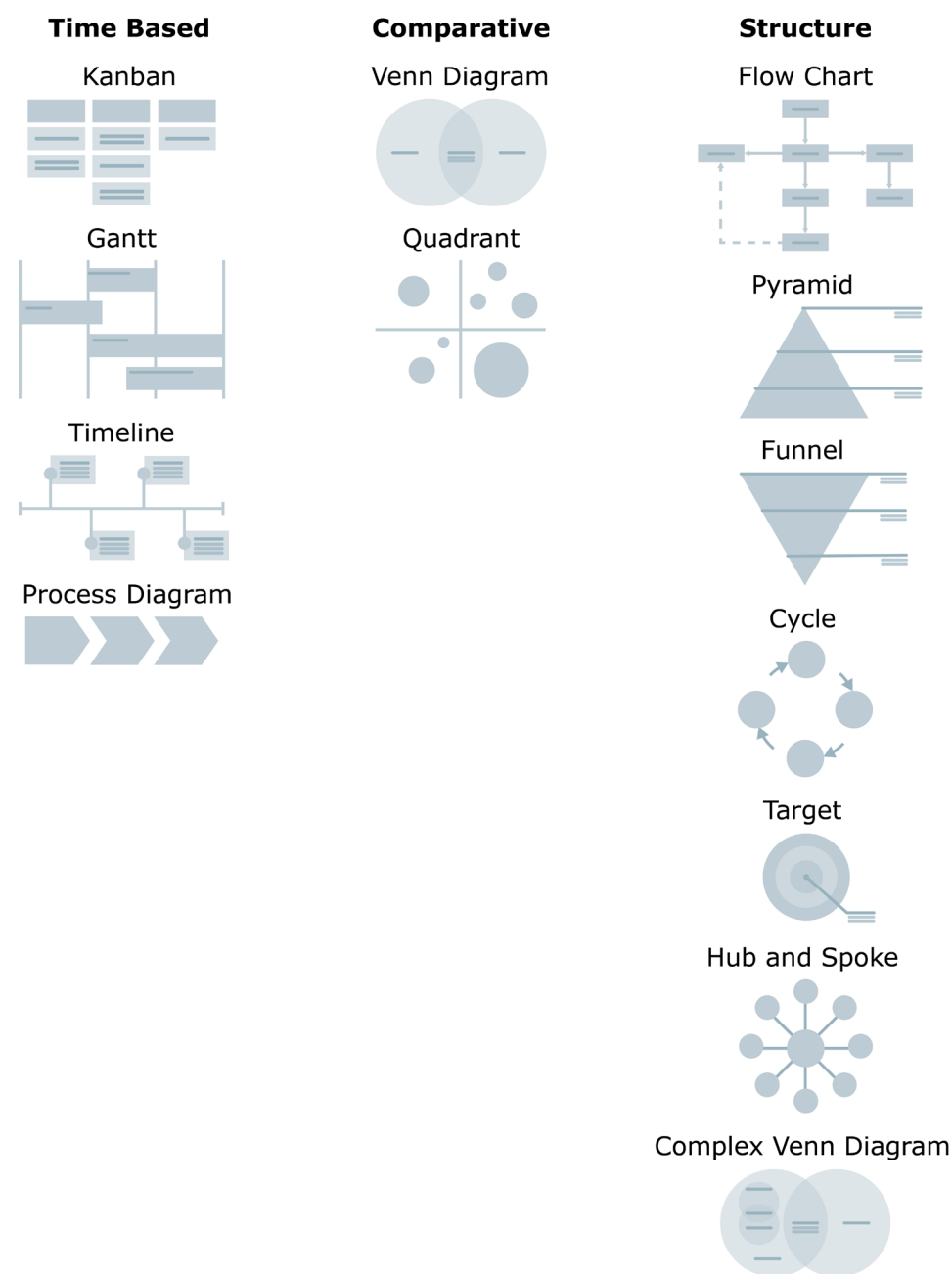

Complex Venn Diagram

Figure 4.2.3. Types of Framework Presets. Different examples of frameworks are displayed as well as sorted into three main buckets: time based, comparative, and structure. The types of frameworks work as preset types that the system uses as a baseline when converting its understanding of a paper to a user.

	Time Based	Comparative	Structural
Analytical			■
Argumentative		■	
Cause + Effect	■		■
Compare + Contrast		■	
Definition			■
Experimental	■		■
Interpretive			■
Method	■		■
Problem + Solution			■
Report			■

Figure 4.2.4. Integration of Paper Types and Frameworks. This table is dedicated to visually expressing the different types of paper types that exist and what frameworks generally work better for the given subject, therefore informing machine learning using the papers what frameworks to pull from when parsing information.

Static   Emphasis   Movement   Time-Based

A

B

C

D

E

F

G

H
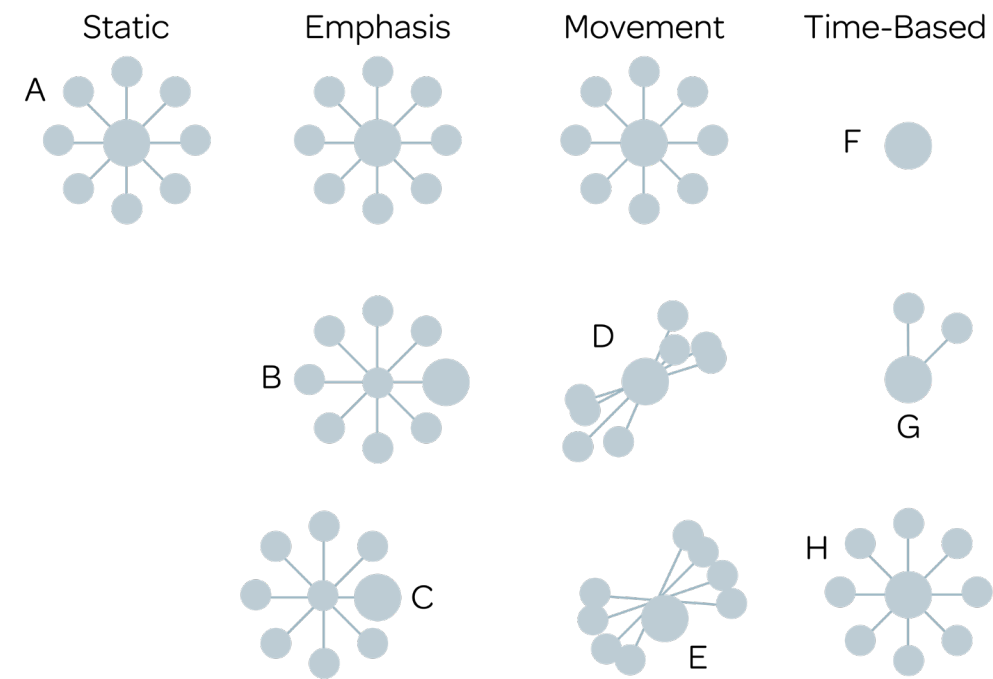
Figure 4.2.5. Hub and Spoke Visual Iterations to User. Figure expresses a visual representation of how a more simple framework may function in different aspects to a user. A) Static meaning the framework appears as is to the user. B) Emphasis in the form of scaling where when interacted with the point becomes larger. C) Also under the form of emphasis and scaling, this example features where when a point is highlighted, it now becomes the center-point for the rest of the framework. D) Explores the idea of the framework being able to move and what that may look like if the user pulled a certain point in a direction and how the other spokes might interact. E) Using the idea of movement, this example shows what dragging the hub around may look like. F) For a situation in which the framework reveals itself over time, it would first start with the base point or hub. G) As time passes, more spokes are added to detail the framework. H) Example features the goal of the time-based framework.

Static   Emphasis   Movement   Time-Based

A

B

C

D

E

F

G
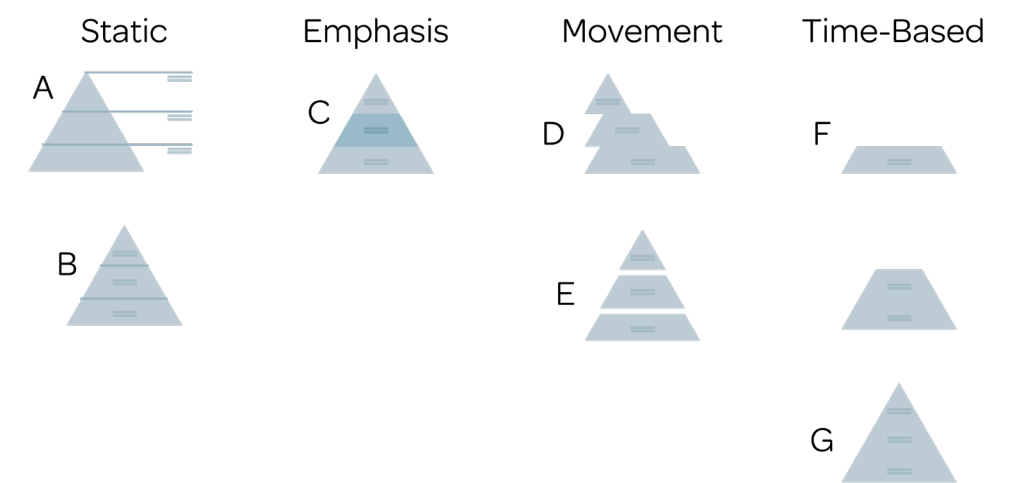
Figure 4.2.6. Pyramid Visual Iterations to User. A) An example is shown featuring a static view of a pyramid-based framework, where the information is off to the side. B) Another example of a static pyramid framework is with the content directly fused with the hierarchy as opposed to off to the side. C) If a user was to interact with the framework, this example looks at showing that interaction through an emphasis of color change. D) User interaction through movement is shown in this example where the pyramid framework is being dragged and the other parts move to keep up with it. E) Exploring another form of movement is if the separate elements of the framework float separately to create a level of visual layering. F) Looking at time-based explorations, the first step would be the base of the pyramid as shown here. G) After time has passed, the framework builds up in layers to complete itself.

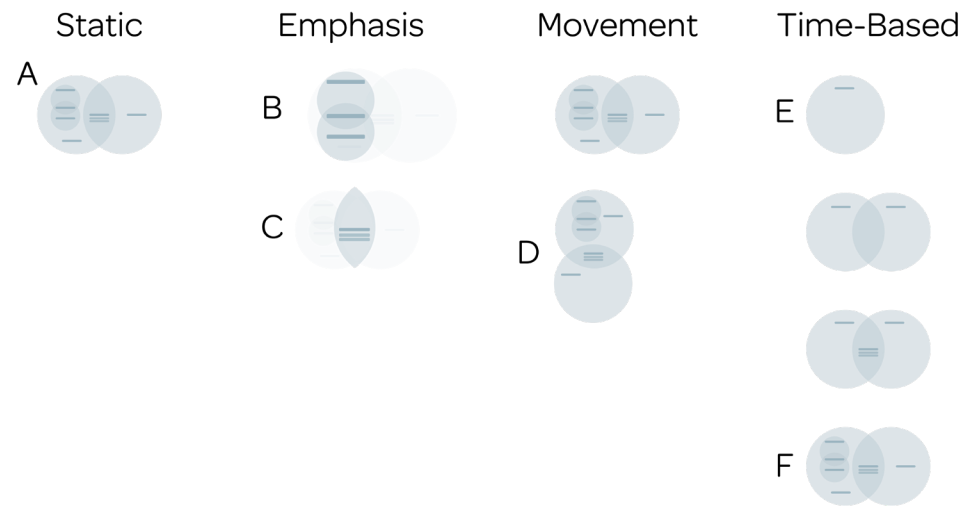Static   Emphasis   Movement   Time-Based

A

B

C

D

E

F

Figure 4.2.7. Complex Venn Diagram to User. A) A complex Venn diagram is a Venn diagram with more elements of comparison to build depth within a framework, in this example, it is shown as the control state. B) Looking at emphasis for exploration, this example looked at emphasis through scale and opacity, zooming in on clicked comparisons and fading out the rest. C) Keeping with the same core principles of the last exploration, this one shows a different element of the complex Venn diagram being emphasized. D) Since Venn diagrams are specifically circular based, movement exists here where elements pivot and adapt to the change. E) This time-based exploration looks at adding one core element of the framework over time, in this case, starting with one point. F) A final example of a time-based exploration can be featured here where elements of comparison are added as the framework develops.

Time-Based

Clock - Passivity   Progress - Activity
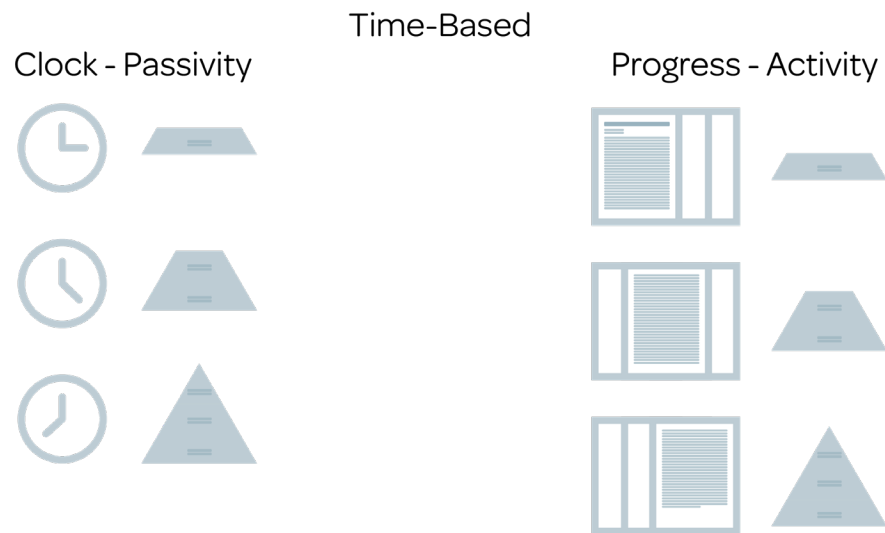
Figure 4.2.8. Time-Based Variations. The left column features a time-based framework builder that works off of a clock. As the system clock counts up, the framework slowly builds. The right column features progress as a form of time-based framework building. With progress, as the user scrolls through the paper, they can visually see the framework construct and deconstruct itself.
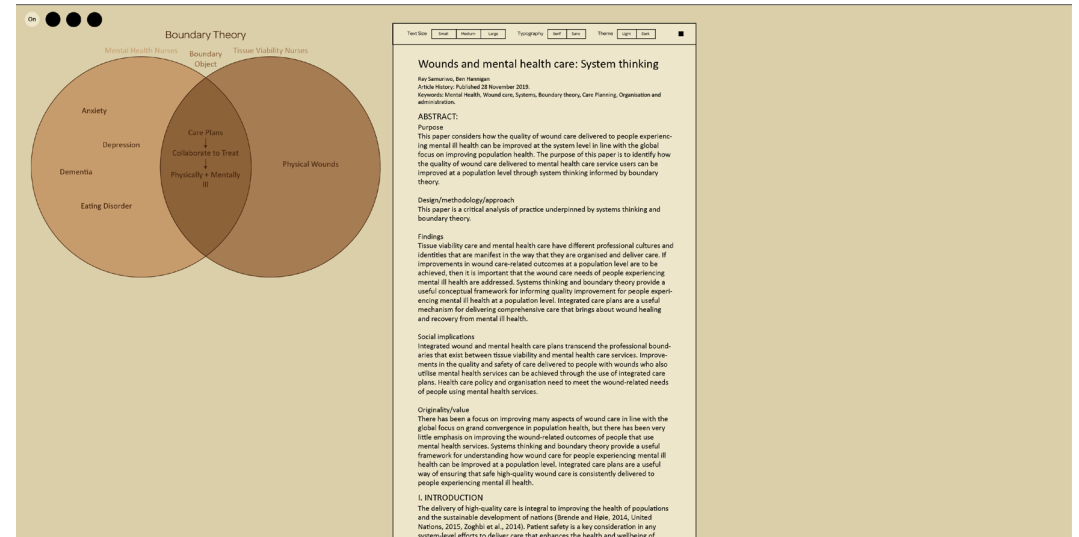
Figure 4.2.9. Static Framework. This Figure exemplifies a situation in which the framework builds itself without any interference from the user.

Figure 4.2.10. Building Through Quizzes. This example shows a question generated by machine learning on the left and when the user selects the right answer, it gets added to the framework, as shown with the right example. The visualization on the left expresses a Venn diagram before an answer is selected so the user has a visual idea that what they are answering for will fill in such
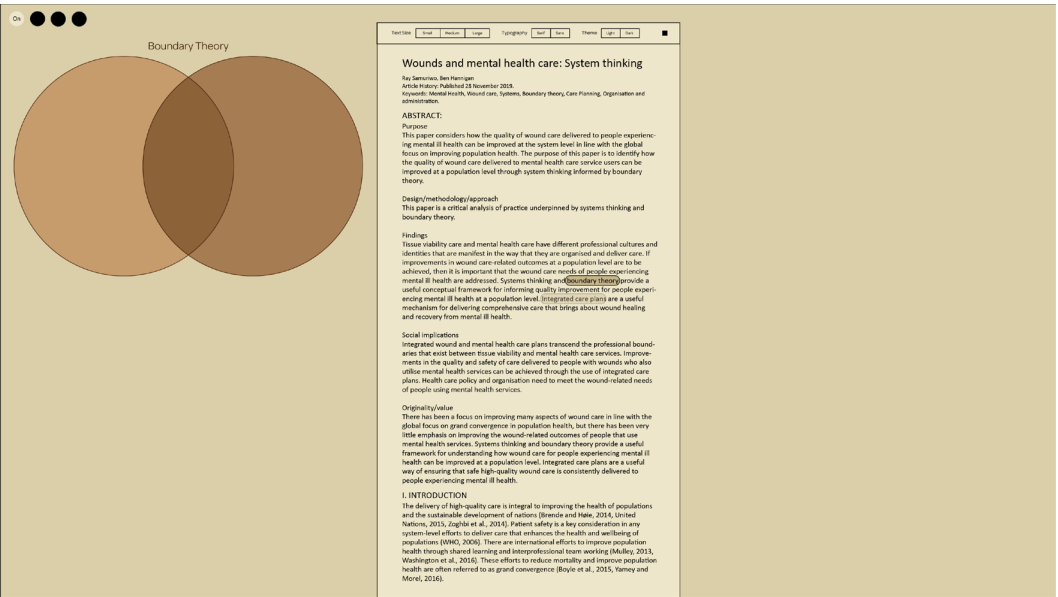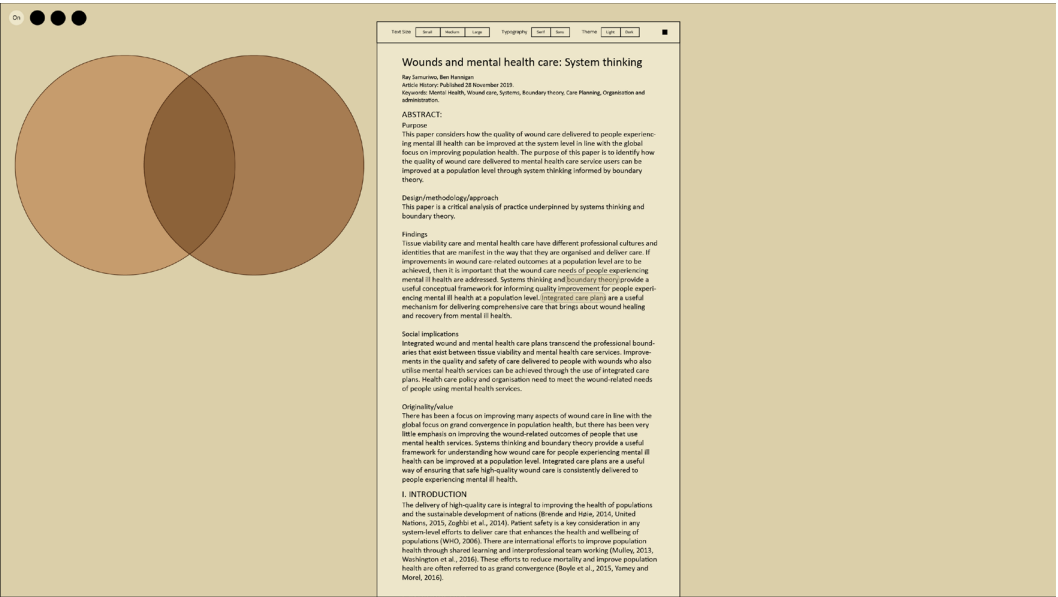
Figure 4.2.11. Search and Find Building. These two visuals look at an example of a basic preset framework in which the system has determined the paper is Venn diagram based. From there, the user while reading through the paper will find terms, phrases, or sentences within the text itself that prompt the user to click and when selected will be added to the framework.
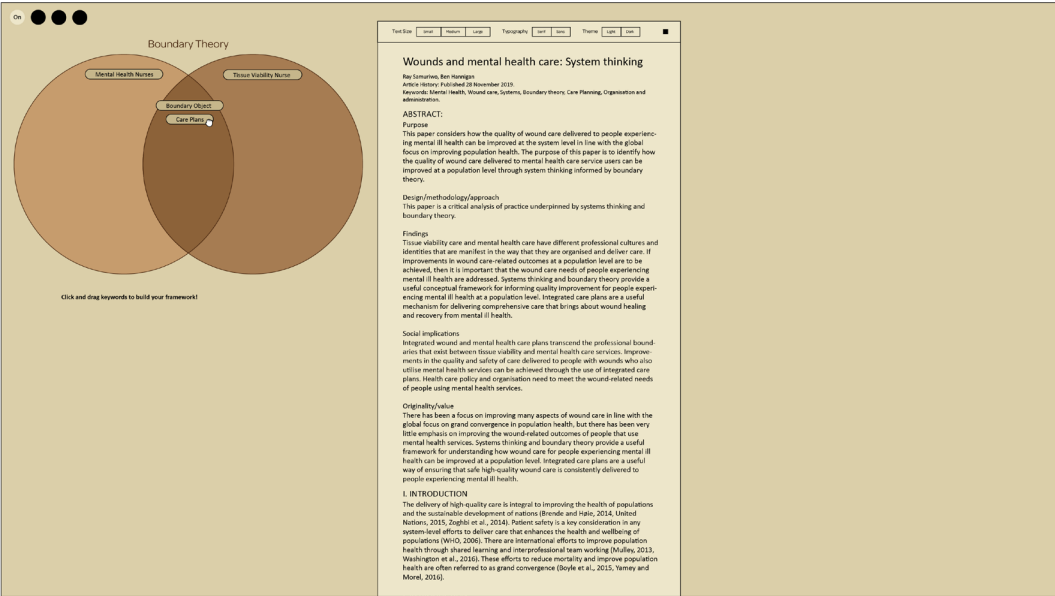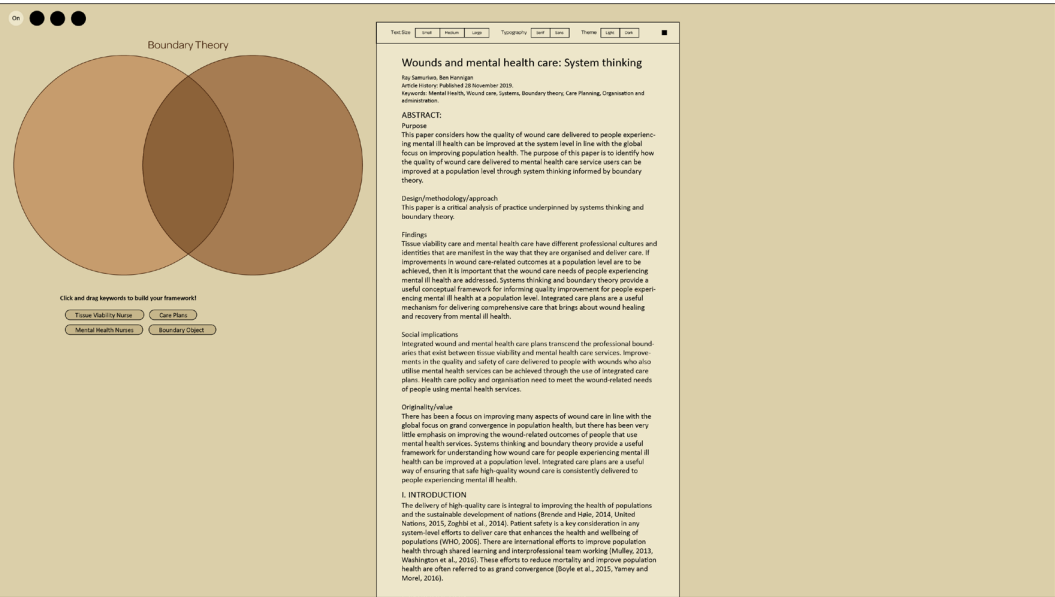

Figure 4.2.12. Keyword Drag and Drop. Using the machine learning integration here to read through the paper beforehand, it generates that this specific paper would work best with a Venn diagram framework and then compiles a list of key terms that were used throughout the paper with key relevance to the title and abstract. The system prompts the user with the main idea via title and then the keywords become modules that a user can drag and place on the framework preset.
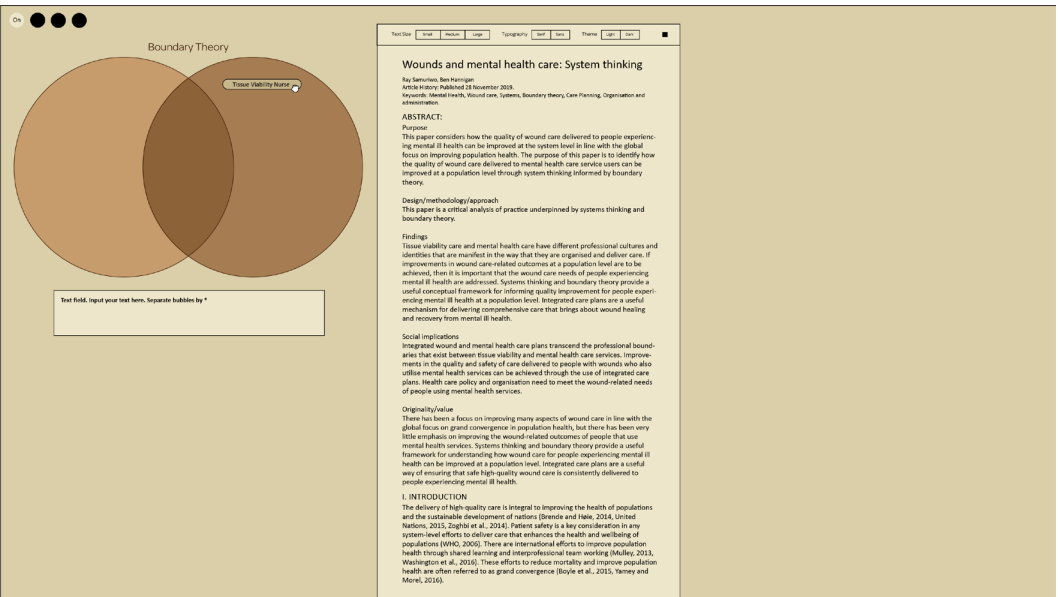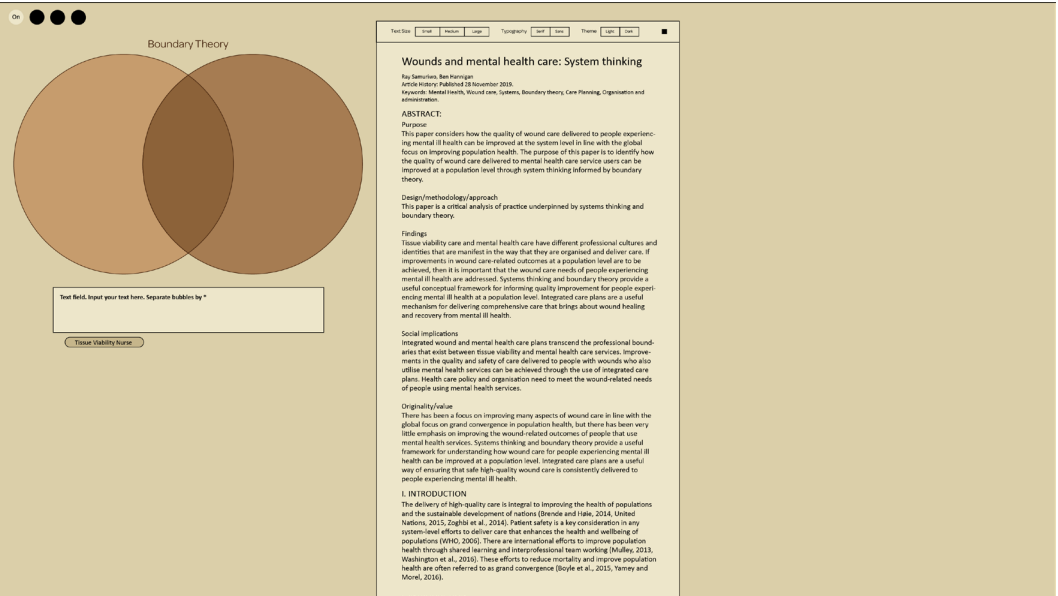
Figure 4.2.13. User Generating Modules for Framework. With this Figure, the user is prompted only by the framework preset and a title by the system. The user then creates their own points of interest as they read through a research paper and makes their own modules to place on the framework.

4.3.   User Interface Synthesis with User Input

Investigation three focused on combining and addressing subques-tions three and four, addressing how user input integrates into the system and how all ideation from earlier studies comes together into one cohesive story through a scenario.

Extension Scenario Synthesis

Olivia is a second-year biology student at North Carolina State University who has recently found out through a psychology elective that she has aphantasia. While it was interesting to find that out, she has had a very specific routine for how she handles learning, to be productive and commit to memory. She actively participates in class discussions and makes color-coded notes to discern different kinds of information as she writes. Unfortunately, something unprecedented happened, like a global pandemic, and she is now forced to engage in classes via online means. At first, this does not bother her as reading through discussion posts from peers and even watching lectures involve a familiar vernacular that she can still engage with. It is not until she gets an assignment to write a literature review on Drosophila gene expression that things become frustrating.

Olivia tries reading through different papers but finds that the information is not sticking and she has no one to talk to in order to verbally digest it and no visuals to create associations with. Growing more agitated with an impending deadline, Olivia reaches out to one of her psychology elective peers who also has aphantasia. This peer, Eli, is no longer a student and is in the psychology department faculty, but he still has to read research and academic papers as well as compile the information into a literature review. He has found an extension that has worked in the past with aiding in association-based reading to make academic writing more digestible.

Olivia sits down one evening and installs the web extension through a virtual store and opens up a PDF file within the browser. The first thing she notices is the toolbar and curiously decides to explore her options. When she finishes clicking around on things, an icon that she did not click on because she was not sure what it did highlights and prompts her to click, as well as informing her that it will reflow the text, as seen in Figure 4.3.1. Unsure about what that means, she clicks it anyway assuming she can turn it off and once done all the text is now in a single column that is not too long and easy to follow through with her eyes (Figure 4.3.2.). She messes with a few more settings at the top of her paper, changing the text size and theme to her desires. Now that she feels a little more confident in her ability to use the tool, she sets out to read through the paper. Right away she comes across a rather unfamiliar word and wants to define it. She highlights it as though she was about to copy and paste it in her browser bar to have Google define it and instead a card pops up to the side that auto defines the word depicted in Figure 4.3.3. While the yellow highlight does work, she prefers using pink for defining words to match her own note-taking methods on paper and changes the highlighter

color to match her preferences. While continuing to read, she finds a phrase she finds important and she highlights it, the card then prompts her to write her own definition for the phrase (Figure 4.3.4.).

After having interacted with the paper at least once, the exten-sion uses the toolbar to highlight another icon and provides a small amount of information about what it can do. It says it is a framework builder and shortly explains itself as expressed in Figure 4.3.5. Once again curious, she decides to activate the feature and is surprised when the other side of the paper now features a graphic (Figure 4.3.6). If more information is desired, it explains that machine learning reads through the paper and picks out information it feels is connected, and compiles it into graphic presets. It also invites her to change how the information is displayed by pointing to a moveable toolbar that has now appeared. The framework starts with just a few bits of infor-mation to it including a preset form and title. She finds she wishes to add a summarized version of the section she just highlighted to her framework, so she uses the text tool and adds it to the frame-work which can be seen in Figure 4.3.7. While continuing her read, the extension adds more keywords (Figure 4.3.8.). She finds that the information seems to be following a model shown on a later page of the paper. Being introduced to it earlier on as she read has allowed her to put the context of information into place. She finds that she is not particularly fond of how the framework added a bit to her timeline framework and alters it by double-clicking the text, allowing her the freedom to change what the system determined correct to make it more meaningful to herself. Thrilled that she can make her own additions while also having things visually and spatially explored, she continues comfortably reading, not fretting every time she comes across a word she does not recognize. As she reads she adds to her notes and the framework, referencing them whenever she becomes stuck with a word or phrase. By the end of the paper, Olivia feels satisfied with the amount of progress she made and ends up collaps-ing her notes to check how many she wrote as shown in Figure 4.3.9. She then scrolls up through the reading to find an earlier highlighted word. With a new understanding of the word and the reference material of the framework, she moves to the digital cards and edits them to put a definition into her own words. While she does this, she notices that the framework actually unbuilds the further she scrolls up, so when she finishes adding her new enlightened note, she tests scrolling up and down only to find that the framework is building as it did when she first read, however, it is also accounting for when she added information. After playing around with this interesting feature that tracks her progress, she scrolls down to the bottom again to check the references and then decides she is finished with the paper and would like to look at another one by going back to the papers hub in the extension toolbar (Figure 4.3.9).

Content with the digital notes that match the style of her lecture notes, she saves the document and moves to the next paper which the hub can be seen in Figure 4.3.10. She heads back to the extension's hub and opens another paper through the extension. It has saved all

her settings so everything is formatted the way she can easily use it, saving her considerable time. Looking at the hub, the thumbnail view of the paper prioritizes the frameworks she made while reading along with the paper. Since spatial relationships are the strongest visual indicator for people with aphantasia, Olivia is easily able to identify what each paper was about and finds that papers one and three are connected (Figure 4.3.11). Paper one looked at the history of Drosophila testing and ended with a general idea of where testing on them could help human understanding, while paper two looked at infecting the Drosophila with a specific virulent to study its effects since it is a human-generated pathogen. She drags one thumbnail onto another and it opens a new tab with only the two frameworks which are shown in Figure 4.3.12. While she understands the two papers are connected, it is not until she sees both frameworks laid out that she can start visually moving pieces together to create a new relationship, progress can be shown in Figures 4.3.13 and 4.3.14. Once she is done configuring, she is able to save her work and a window pops up prompting her to name and give a description to her merged framework (Figure 4.3.15). This new entry pops up between the two papers with a line linking showing that the merged framework sits between the two papers as seen in Figure 4.3.16.

This methodology allows her to save time while writing notes and gives her a visual understanding of mapping out the information in a way that is meaningful to her. This benefits her aphantasia as it gives her a visual for something she cannot internally visualize, but she uses her ability to recognize to commit her paper's notes to memory, allowing for ease of use.

Reflection

The point of this investigation is that it is used for memory recognition to jog an aphantasics memory since they cannot create the visuals in their head and therefore use this piece that they create while reading through, with the assistance of the system, to build those associations for long-term memory and allow for easy memory recognition when looking at the paper later.

For example, someone may associate mac and cheese with their parent because of the many times that parent has made them mac and cheese, but that does not mean they see that parent when they only look at mac and cheese and vice versa. Someone with aphantasia focuses more on the emotional meaning of the connection, rather than the visual association. Tying back to the investigation, the point is to make a visual where every node means something to an individual because they built that connection while reading or creating the node. After establishing this spatial relationship for recognition, they can come back at a later point and glance at the visual that is designed to trigger an aphantasics memory, and remember what the paper was about without having to read the information again. This is to replace the general visual memory one can have by reading a trigger phrase and having the stored visual in their head pull up that many are

capable of. The goal is to give that mapping an actual visual form to those that cannot map it out in their heads and then use that to help memory recognition in people with aphantasia.
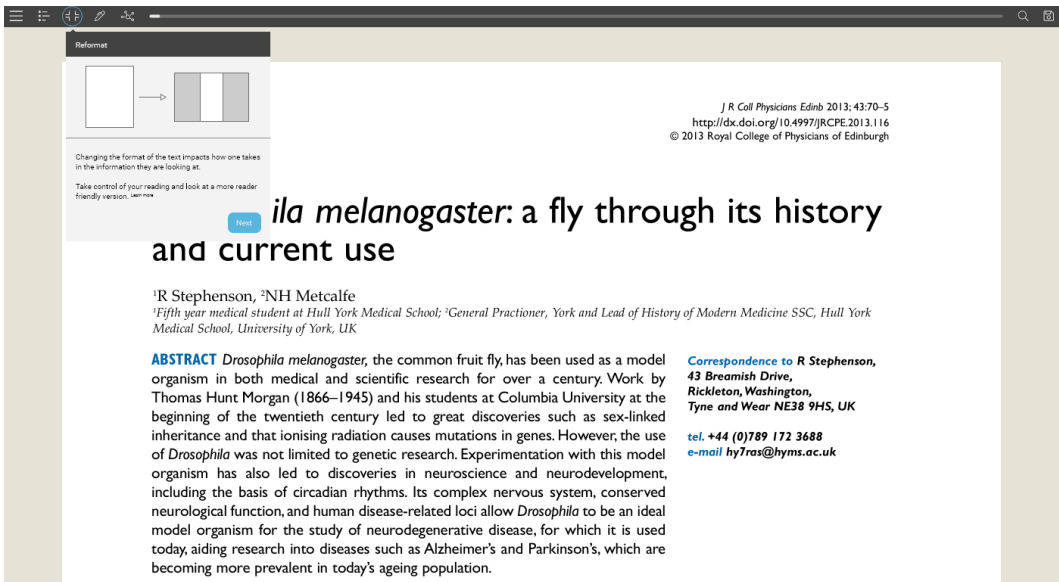
Figure 4.3.1. Reformat Text Prompt. Featured is a regular science research paper that has been uploaded to view and a toolbar from the extension, prompting the user to click an unfamiliar icon while giving them more information on what the reformat option does.
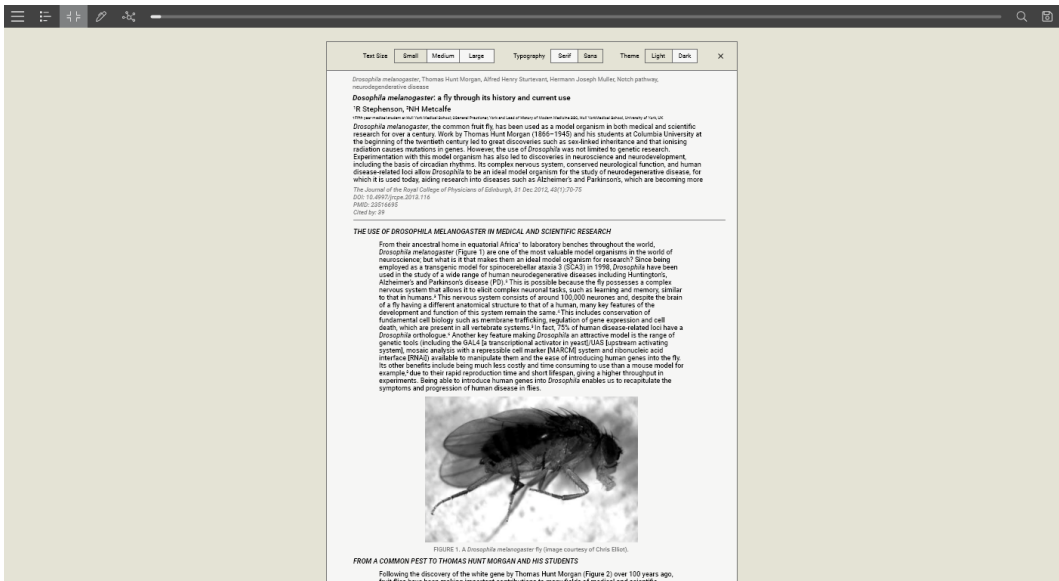

Figure 4.3.2. Reformatted Text. Figure expresses reformatted text in a more digital-friendly way allowing for the user to make small changes to text size, typography, and theme color so they are more comfortable looking at the information they will be addressing.
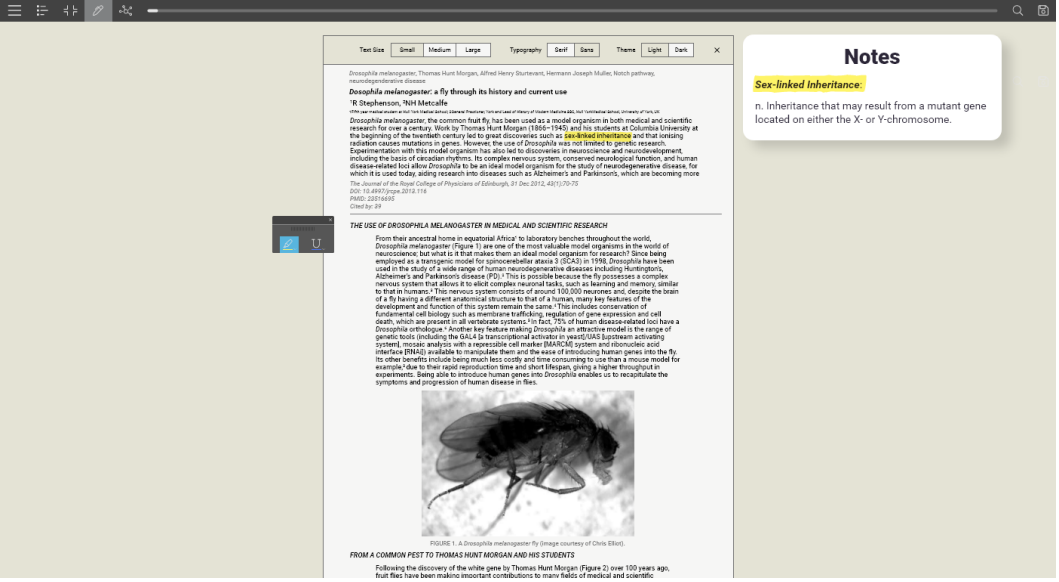
Figure 4.3.3. Starting Note-Taking. Found in this Figure, the user finds a word they wish to know more about and highlights it with the highlight tool.
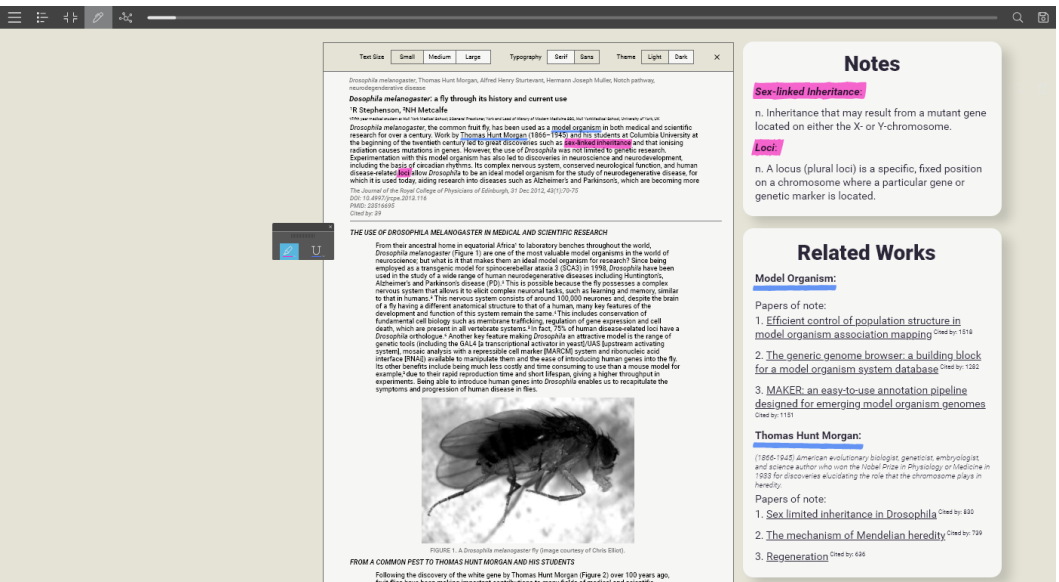
Figure 4.3.4. Read Through the Abstract. This Figure shows the use of the notes and related works cards as well as the user changing the default color to a color that is more comfortable to them. The notes section defines what is highlighted while the related works section looks up relevant papers to the underlined names or things.
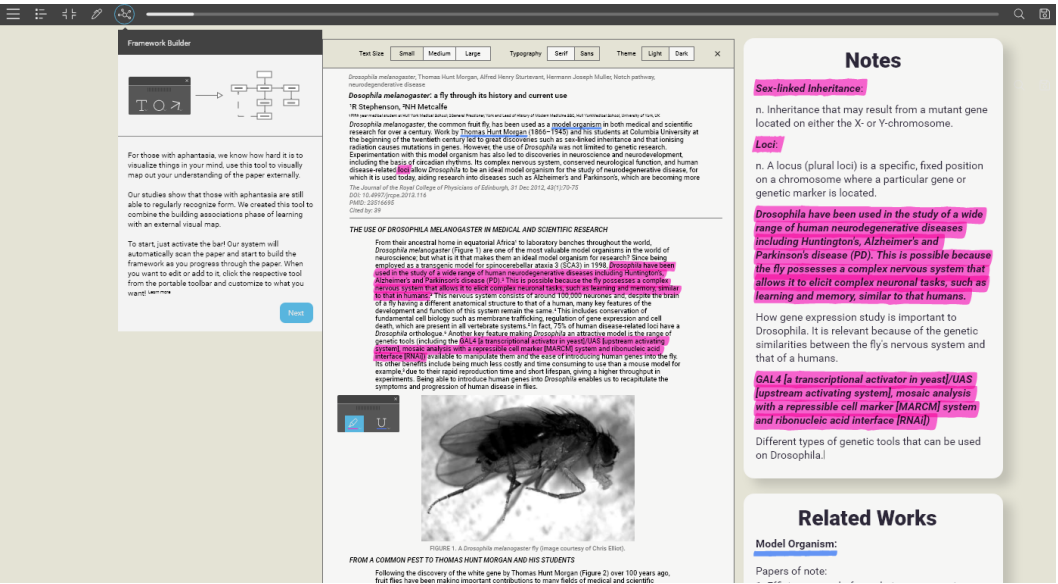
Figure 4.3.5. Framework Prompt. Highlighted in this Figure is the framework's prompt, educating the user on what the tool does before selecting it. Also featured is more text highlighted, but this time instead of it being something easily identifiable, the user fills in this large selection of text with a definition of their own.
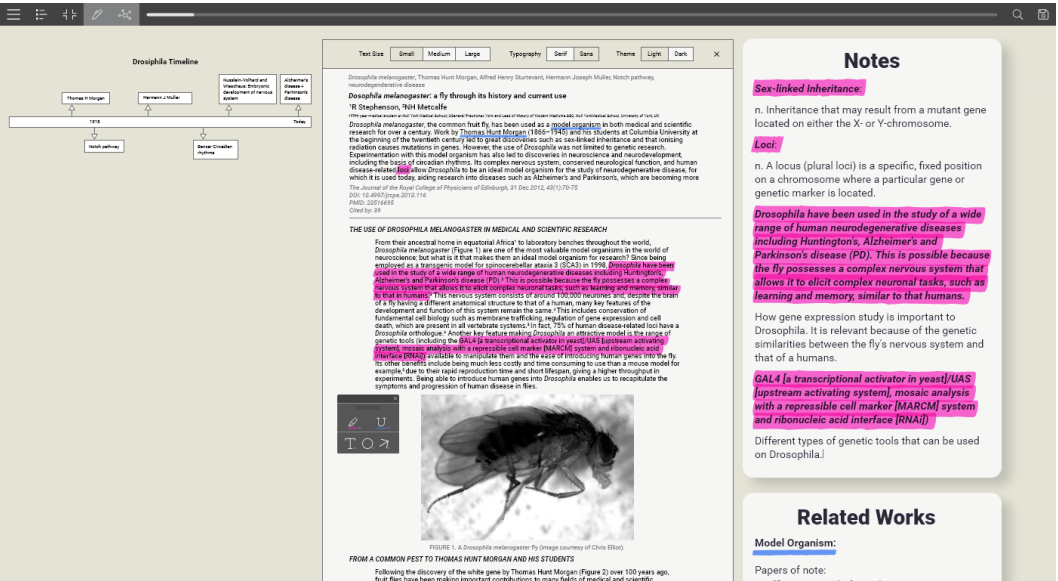

Figure 4.3.6. Framework Without User Input. Depicted is the system reading what the user has interacted with thus far via their note-taking tools and converting that into a framework. The system knows how it will end, but is selectively expressing information back to the user so they can see where that information is actually coming from.
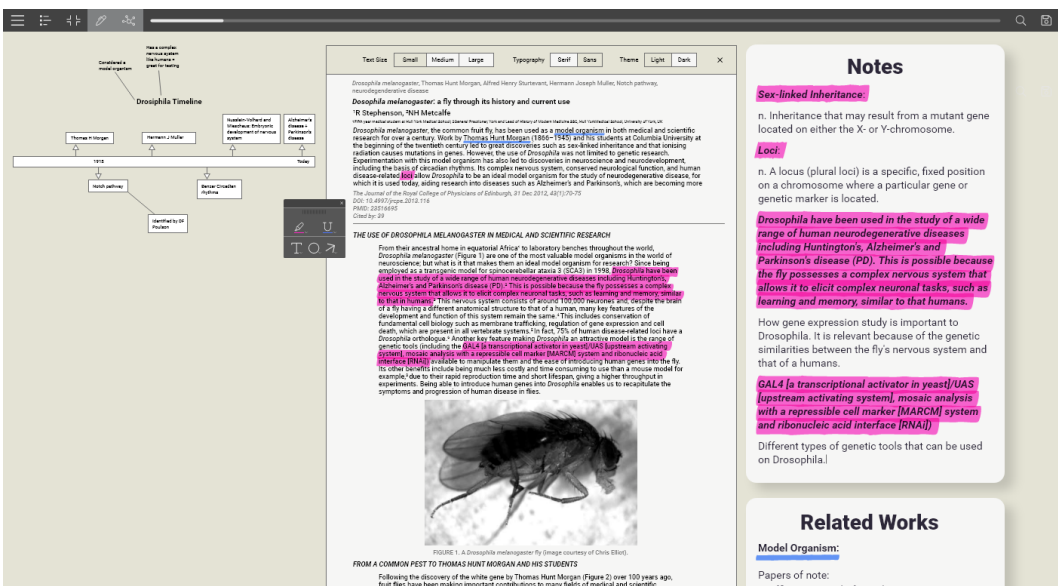

Figure 4.3.7. User Builds on Framework. This Figure shows the user using the framework building tools, and adding lines, shapes, and just plain text to the document. This simple little toolset has a click and hold feature with more available options underneath. For example, shapes are not limited to a circle, as the user made a rectangle. The line tool also features different kinds of lines such as solid, thick, and dashed.
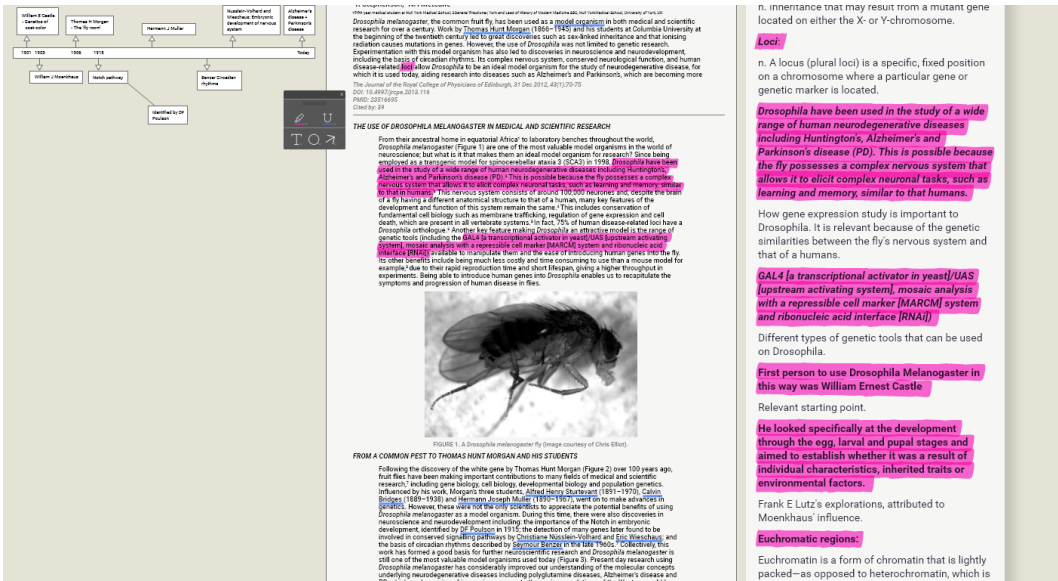

Figure 4.3.8. Framework Builds Through Time. Visually depicted in this Figure is the user reading more throughout their paper and the system adding to the framework and filling more information in as it becomes relevant.
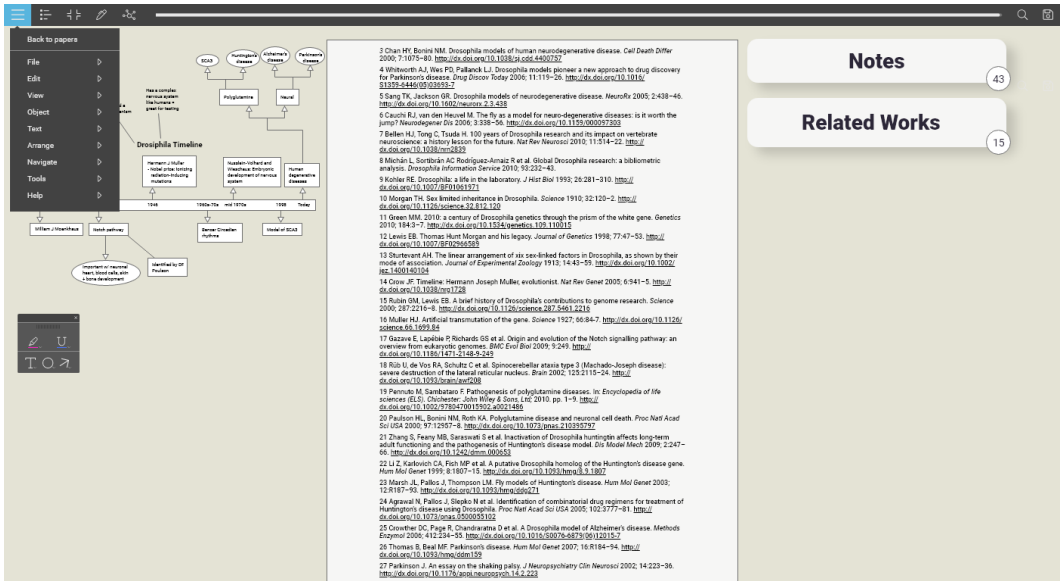
Figure 4.3.9. Finished Framework with Back to Papers. When a user finishes a paper, they can see their completed framework, as well as use the hamburger menu to get back to the papers hub. Also featured here is the ability to collapse card categories on the right with indicators of how many notes exist.
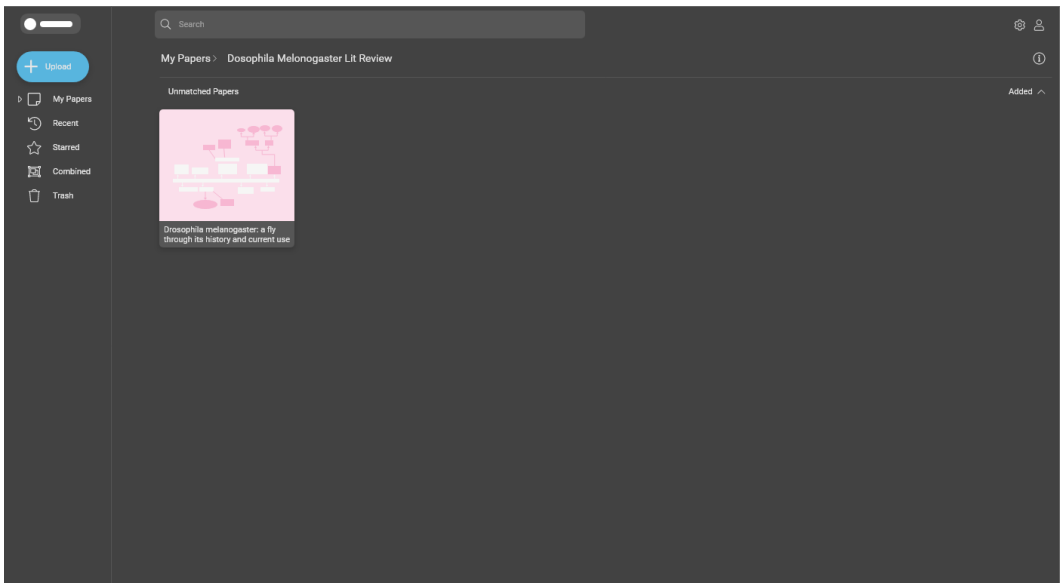

Figure 4.3.10. Papers Hub. Investigated here was how the document hub would look. It would have basic features for uploading new papers, as well as featuring a thumbnail depicting only the shapes used for the framework the user-built while reading. A random color is given to every paper, and an emphasis on that color is used here to show what the system created and what the user-modified or added on their own. Underneath the framework thumbnail is the title, and these two aim to jog an aphantasics memory by playing on spatial cues and memory retention.
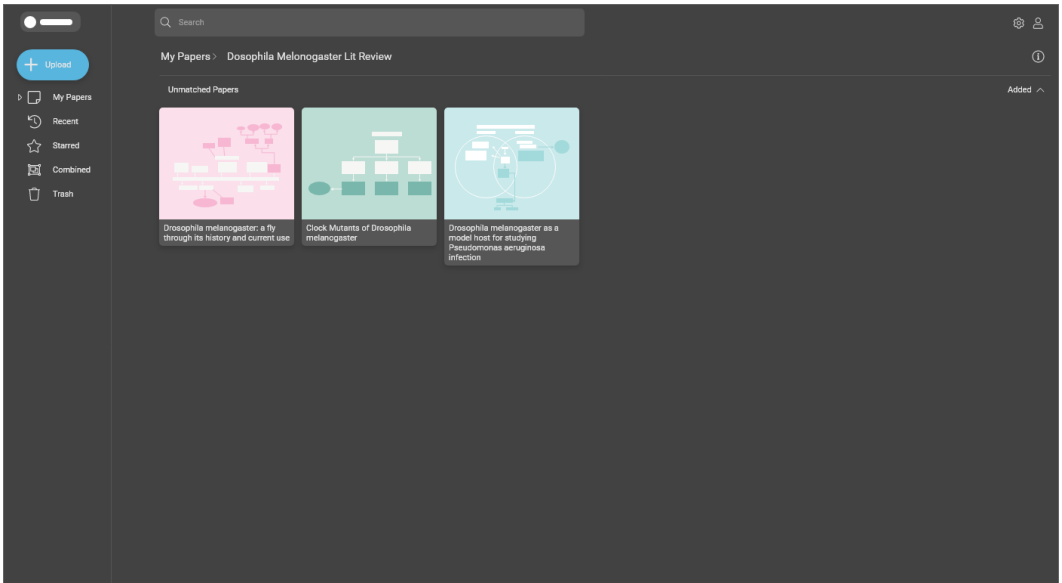

Figure 4.3.11. More Papers Uploaded. When a user uploads more papers, they function in a tile-card modular form. These papers are sorted into a folder based on a user-determined topic and despite being under one bucket of topics, the papers are unique, allowing for unique frameworks from each reading, aiding in recognition later.
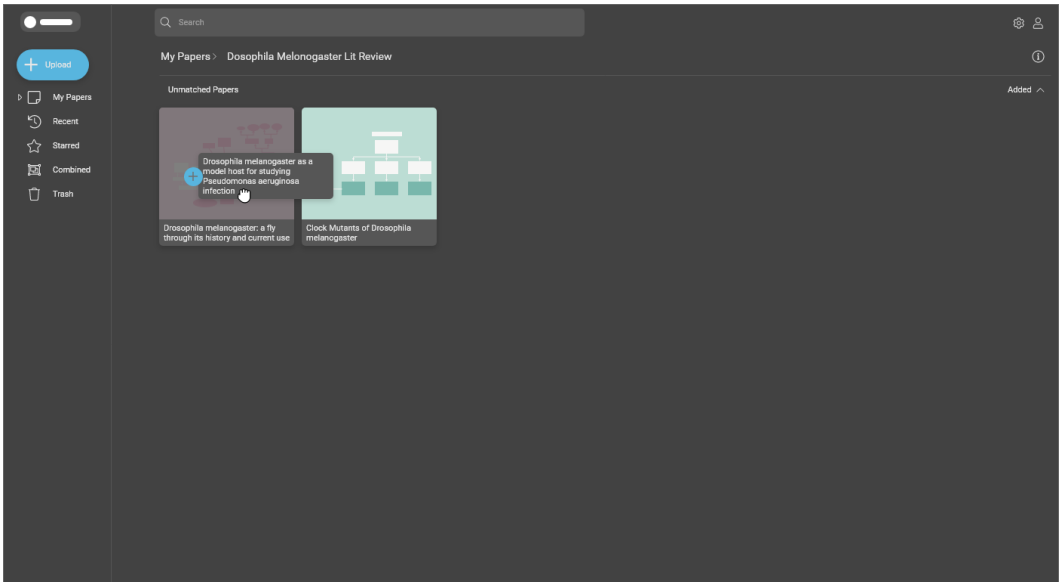

Figure 4.3.12. Combining Papers. Shown here is the reliance of the previous Figure graphically to depict the dragging of the right-most framework onto the leftmost framework and how a plus is added, implying when let go that interaction will take place.
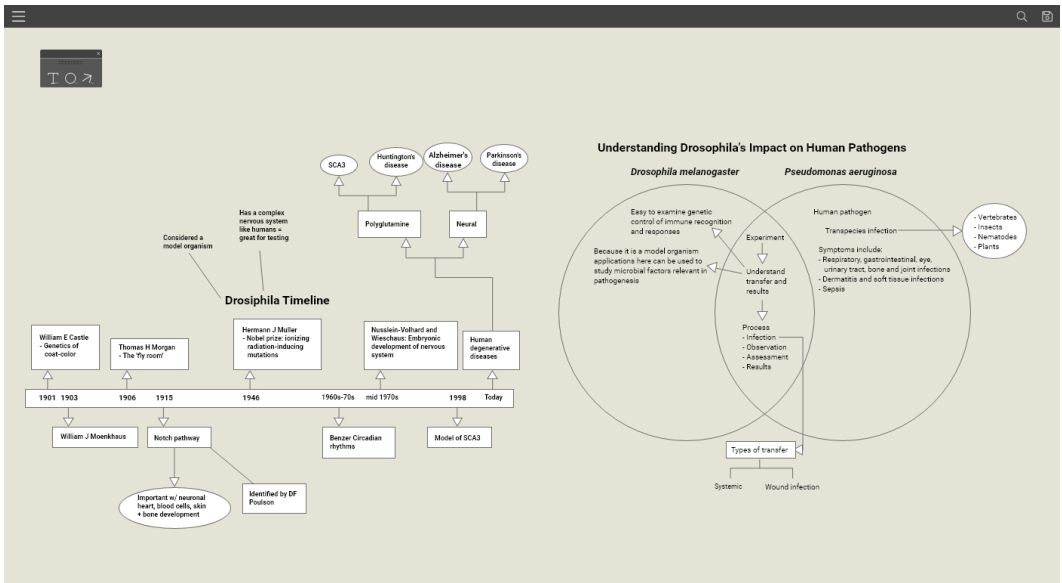
Figure 4.3.13. Combining Frameworks. Shown here is a look at untouched two pulled-in frameworks looks in the framework merge mode. A reference of the actual text papers is not shown because these frameworks are relying on the user's memory recognition abilities to decipher what the papers were about and make new meaning when building a visual together.
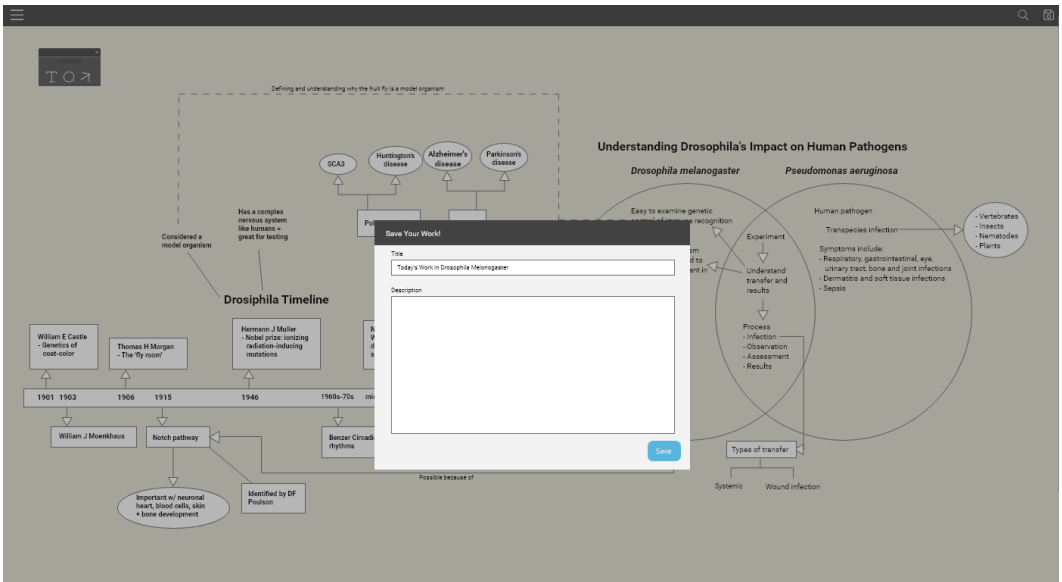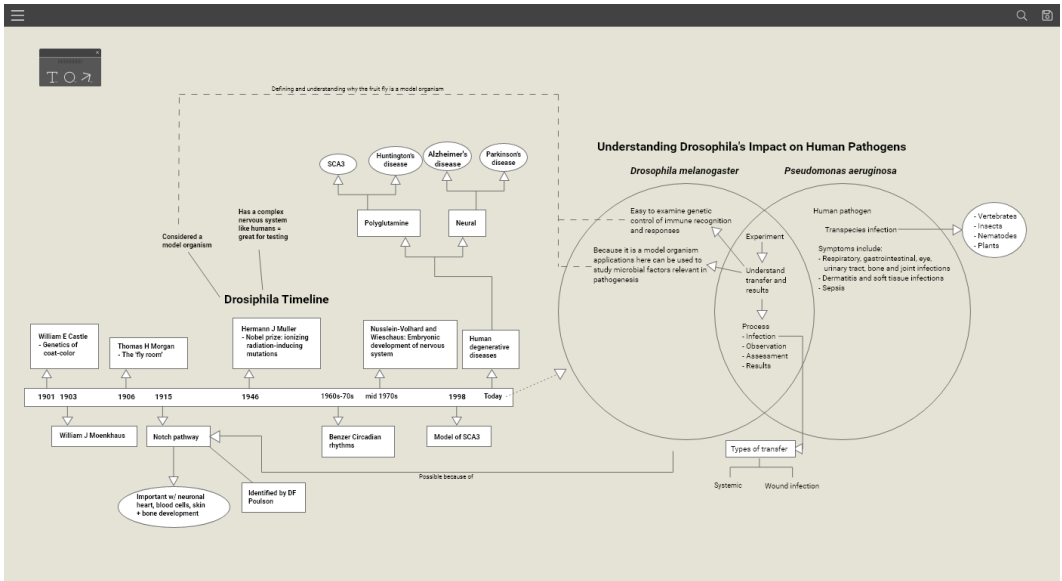

Figure 4.3.14. Finished Combination of Frameworks. The user has used the framework building tools to create new relationships between the two frameworks, making sense of how the two relate to one another.

Figure 4.3.15. Saving Prompt. A user can easily save a title and a short description of what this merged framework means to them.
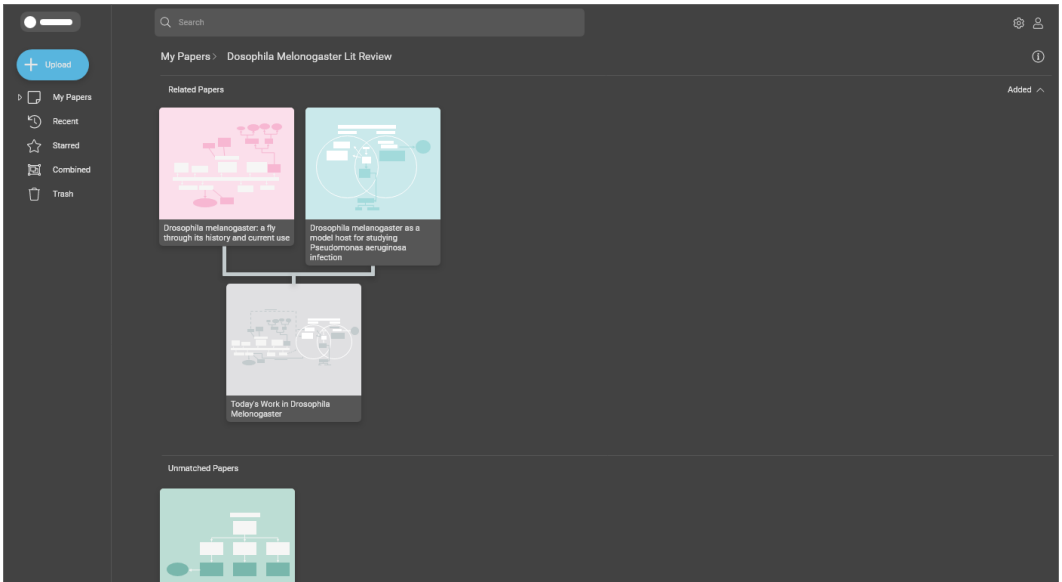

Figure 4.3.16. Papers with Relationships. Shown is a parent relationship with the child merged framework in the center, in relation to the other papers. The other papers that are not a part of this relationship are pushed to the side until a connection is drawn between them.

5
DISCUSSION

5.1.   Design Principles

This investigation focused heavily on exploring how the system may function and what its capabilities are in the context of a user with aphantasia. Throughout the process of research and design, several core principles were established that can also be applied outside of this investigation to other designers and environments.

Create Consistency Using Real-World Applications. Through the later stages of research and the design stages of my investigation, it became apparent that due to the associative nature of thought and the reliance of that in those with aphantasia, that converting real-world applications to digital and keeping the language the same would inform a more cohesive system to the user. For example, many tools could have been developed, but grounding the tools in what an individual usually has at their disposal when taking notes, it allows for the user to feel more comfortable when entering the digital environment. Because the nature of the work here is already so intense with material and vernacular, it is important to reduce having to have a user learn a whole new design language to easily operate an assistive tool. Thinking about the user and whether grounding design in the form of existing applications or exploratory ones was vital to figuring out the direction of many studies within this overall investigation.

Increase Usability by Reducing Cognitive Load. While a designer's general goal is to reduce the cognitive load of a user, it was apparent that while designing this system and thinking of usability features, the effects of having too many options were considered. Many things were designed with the intent of only expressing what is necessary to show or have available so as to not overwhelm the user while they deal with an already mentally taxing task. In this case, the portable toolbars in Study 3 can be found to have reduced options on them in order not to overwhelm a user, however, they still have the option of clicking on the toolbar and selecting a new object (the shape tool from circle to rectangle). Designing with an intent to increase usability via augmentation of a user's digital experience can reduce stress and understanding what that augmentation means or how it comes across to the user was a vital part of this investigation.

Foster Relationship Building Through Spatial Arrangements. Through research, it was found that understanding spatial arrangements is not impaired in those that have aphantasia as well as it also being the strongest form of remembrance for them, in terms of visual cues. This ideology is what informed many decisions throughout this process, for instance, while color may function as a strong visual cue for attention-grabbing, it did not facilitate as strong connection to memory recognition, thus the design work and the center of the framework builder are built upon the spatial arrangements to build associations for long-term memory.

Allow Personalization Principle to Ensure Human Curated Consistency. During the iteration stage of this investigation, there were several examples looking at how the system might handle something versus

user agency. However, due to this being an assistive tool for learning, it became increasingly important to allow the user the ability to have agency over how they wanted their experience to go, this, in turn, fostering a sense of consistency created by the user. Making sure that everything functions at the user's pace is vital to allowing them the space to feel comfortable enough to work on a mentally demanding task. An example can be found in the alteration of the framework found in Study 3. By allowing the user to make their own mark despite what the system says, they are effectively determining what it is they want to get out of the system and letting it function more as a facilitator than a dictator of information.

Engage Memory Recognition for Learning Via Inclusive Design. A way to tackle the idea of inclusive design within this investigation was to break the goals of the project down. By understanding what it was that was desired to be inclusive and to whom the focus was, a precedent was set that allowed for setting a strong foundation from which inclusion could happen. The concept of this investigation became focused on the engagement of memory recognition as a tool to help remember information committed to long-term by building associations to it. Understanding this and applying it to a concept such as "learning" informed a few design decisions, such as addressing what information was relevant for remembering, what information needs to stand out for memory recognition, and what tools are necessary to build a relationship between the task and the individual using it to glean information.

5.2.   Future Work

An important aspect of any investigation is utilizing time to address where work has the potential to go, and as a designer, the work is never quite finished. At present, there are several different features and discussions that this investigation could prompt.

Use Collaborative Annotations. The scope of this investigation was on the individual, but there is a capacity for integrated and even collaborative environments that could utilize this. For example, a classroom where the instructor is trying to explain or break down a piece of academic literature to a group of students and letting them come up with their own understanding. In doing so, this allows for ease of communication by the student or peer synthesis.

Explore Other Cognitive Resource Heavy Literature. Textbook reading is another type of literature found in academia that can be very dense in terms of content and uses up one's cognitive resources, making the task more demanding than another type of literature. Combating that by looking past the narrow scope of academic literature in the form of research papers allows for more avenues that this resource may help an individual.

Expand Past Academia. This investigation focused heavily on the use of an extension to aid memory tension in the form of frameworks for academic writing, however, there is a potential that this could expand to other fields in which dense text is used, for example, looking at terms and conditions or even many different kinds of legal paperwork. This could help beginners in that field make sense of the language used and help experts communicate their findings to non-experts.

Incorporate Other Learning Tools. One thing that was not explored much, as a lot of the research tied to aphantasia talked more about spatial cues being the strongest form of visual memory recognition, was that of vocals. It would be interesting to incorporate the use of verbal techniques to strengthen memory and potentially make the system feel more like a personal assistant (more human-centered) than a tool (more system-centered). Another learning tool that is interesting to explore is that of visual signage for difficult words. By using a sign or an icon to indicate the meaning based on the individual's own experiences, this could speed up the process of understanding.

5.3.   Conclusion

The core of this investigation focused on existing data of aphantasia and used that as a foundation for understanding how to ground this project in reality. When discussing reality, the term is used to define a type of design and research approach by straying from speculation to deliver results. While understanding what aphantasia is and how it functions, gaps were found where assistance tools could be placed to support their growth. There was not only a lack of information on aphantasia and teaching or learning methods, but also a distinct lack of tools to help these individuals who might not have the developed skills necessary to conquer certain tasks. Individuals with aphantasia often learn their own mechanisms for navigating through reality the older they are, hence the chosen audience of college students first engaging with mentally resource-heavy literature. This educational extension was designed with the intent of being used today so that a change may happen as awareness spreads to this increasing group of people who are unaccounted for in the academic department. The groundwork laid here is subject to change, meaning as the field of research evolves on the topic, however, the work present should function as a starting point to bring awareness and provide a foundation in which more inclusive features or systems can be built.

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6
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