Digital Media Design: Final Capstone Proposal

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August 4th, 2019
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1. Project Scope

1.1 Project Title

3D-Printing the Human Brain for PubMed Interactivity

1.2. Project Goal

Constellations of neurological biomarkers underlying any given disease, especially mental illnesses, are rapidly emerging patterns in neuroscientific literature based on findings in medical imaging. These are exciting advancements in the phenotypic categorization of psychological disorders previously only observed and defined by statistics of outward human behavior and cognition, without physical correlates, as catalogued in the Diagnostic Statistical Manual of Mental Disorders (DSM).

The details of the immediate deliverables of medical imaging, namely voxel-level data produced by Magnetic Resonance Imaging (MRI) scans, are at once scientifically rich and not easily navigable beyond interpretations of medical professionals and highly trained researchers. The conventional form of access for most is via publications in medical journals, many accessible through the free online search engine, PubMed, provided by the United States Library of Medicine.

While text-based search strategies are innumerable for online academic publication databases, there is an opportunity to bring these findings to life via compelling, even artistic representations of subject matter. In this project's case, grey and white brain matter.

For my capstone project, I plan to build a 3D-printed interactive model of the human brain that controls the navigation of a single-page web application. The product will be a research tool for psychology and neuroscience as well as an artistic exploration. The web application will react to user interactions with the brain model, mirroring interactions in easy-to-understand and eye-catching visualizations of the brain on-screen, and triggering searches of PubMed databases.

In addition, noteworthy attributes and quantities of search results will be stored within a backend database and used to train a prediction model around queries. The model will be used to empower the user with insights as they navigate within the application.

1.3. Learning Goals

Since I already work on a daily basis as a software engineer, the goals of my capstone will be to stretch my abilities beyond my comfort zones in software. These goals are formed around topics that have long interested me, but I have had little opportunity to explore. My goals will be to:

- modify, enhance, and render 3D model files using a modern 3D modeling software;
- understand and use 3D printing technology;
- explore physical computing fundamentals and design a working system of electronic interactions;
- exercise advanced-level frontend visualization techniques;
- and exercise intermediate-level predictive modeling and applied machine learning (stretch goal).

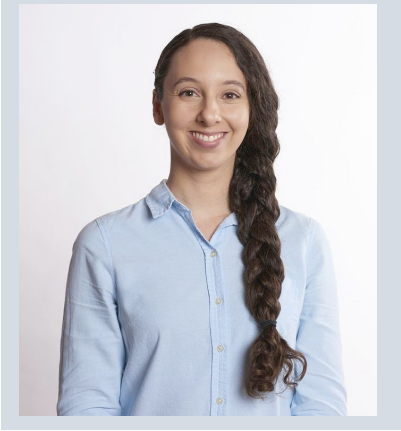
1.4. Target Audience

This design exploration of the human brain as a form of visual and physical academic navigation has implications in research as well as education. The project will be a proof of concept with physical representations of larger anatomical regions (lobes and/or clinically significant areas, the prefrontal cortex, for example). Such a project would have immediate applications in K-12 and undergraduate-level education, but the mechanics could feasibly be extended into applications for graduate, post-graduate, and medical education beyond the proof of concept by increasing the granularity of representation (linking physical points to their voxel correlates).

As a rough estimate for the number of potential users, according to figures from the National Center for Educational Statistics for 2015-16 alone, 117,400 students earned bachelor degrees in psychology, 113,749 in biological and biomedical sciences, and 288,896 in health professions and related programs. Such students, routinely tasked to search the content of academic papers, might be the most interested to use this as a learning and research device. More likely than serving individual users, it could be mass-produced as a classroom tool for thousands of schools.

To further define the target audience, three user personas with empathy maps follow: 1) Taylor, the research assistant, 2) Alex, the college student, and 3) Kelly, the layperson.

PERSONA #1: TAYLOR, THE RESEARCH ASSISTANT



NAME
Taylor
AGE
23
GENDER
Female
LOCATION
Boston, MA
OCCUPATION
Research Assistant at a local hospital
EDUCATION
BS in Psychology

GOALS AND MOTIVATIONS
For work and her own career advancement, Taylor needs to sift through hundreds of research articles on PubMed and other academic databases on a regular basis. Taylor needs to be able to comprehend and summarize her findings, connecting together big ideas through the minutiae. Hoping to move on and pursue a PhD in neuroscience, she is also simply passionate about learning more about the brain.

ENVIRONMENT
She has a laptop at home, but working in a research lab at a local hospital, she is limited to a Windows machine with dated access to software. She is able to use Chrome.
QUOTE
"There's supposed to be 100 billion neurons in the brain. If PubMed only has 30 million articles, total, then I guess academia's barely at the beginning of what we need to understand in neuroscience… so really, can't complain about writing 100 citations."
CREDITS
Image by Robin Higgins from Pixabay

Traditional PubMed Experience: Taylor's Empathy Map

Think & Feel

I wish I had more time before the deadline to read all this.

How are there not more convenient ways to slog through this?

This is so time consuming.

Hear

Can you summarize the patterns you're seeing so far?

Just look at the papers with the most citations.

Just find the p values first.

See

I have to dig through the links to get to the useful graphs.

The search result list doesn't even include abstracts.

Say & Do

I wish I had time to look into my own research ideas.

This is fascinating but there's just not enough time for every article.

Pain

Hours and hours-- mentally exhausting.

Wasting time with irrelevent results.

Gain

Exhaustive / comprehensive results.

Confidence in findings given enough time.

PERSONA #2: ALEX, THE COLLEGE STUDENT

NAME
Alex
AGE
19
GENDER
Male
LOCATION
Seattle, WA
OCCUPATION
Retail Worker
EDUCATION
College Student (undeclared)

GOALS AND MOTIVATIONS
Alex has an *Intro to Neuroscience* class he's really excited about. Now that he's getting the fundamentals about the physiology of the brain and how they might impact disease, he just wants to be able to explore on his own. He can navigate around academic databases online pretty well, especially with some topical starting points from class, but he wants to be able to explore far and beyond the skeleton of his syllabus.
ENVIRONMENT
Alex primarily uses a MacBook Air for school and prefers Firefox.
QUOTE
"Although there's a specific area of the brain for olfaction, for example, I want to understand and see for myself how that information is transmitted through other areas of the brain. How can I see a bigger picture of that?"
CREDIT
Image by SD5432SD from Pixabay

Traditional PubMed Experience: Alex's Empathy Map

Think & Feel

I can look for papers similar to what the professor cited.

I'm overwhelmed! I just need to focus on what I need for my paper.

I need to wrap my head around these concepts *fast.*

Hear

Here's a list of authors you'll want to look for.

Pay close attention to the hypothesis of each experiment.

See

I'm sort of a visual learner and these mountains of text are hard to navigate.

The autocomplete search box is a little helpful.

Say & Do

How do I explore something beyond what's covered in the syllabus?

I'll just do a *little* skimming on Wikipedia...

Pain

Hard to know where to look or branch off.

All the scientific terms are still sinking in.

Gain

It's cool to read a step past pop science articles.

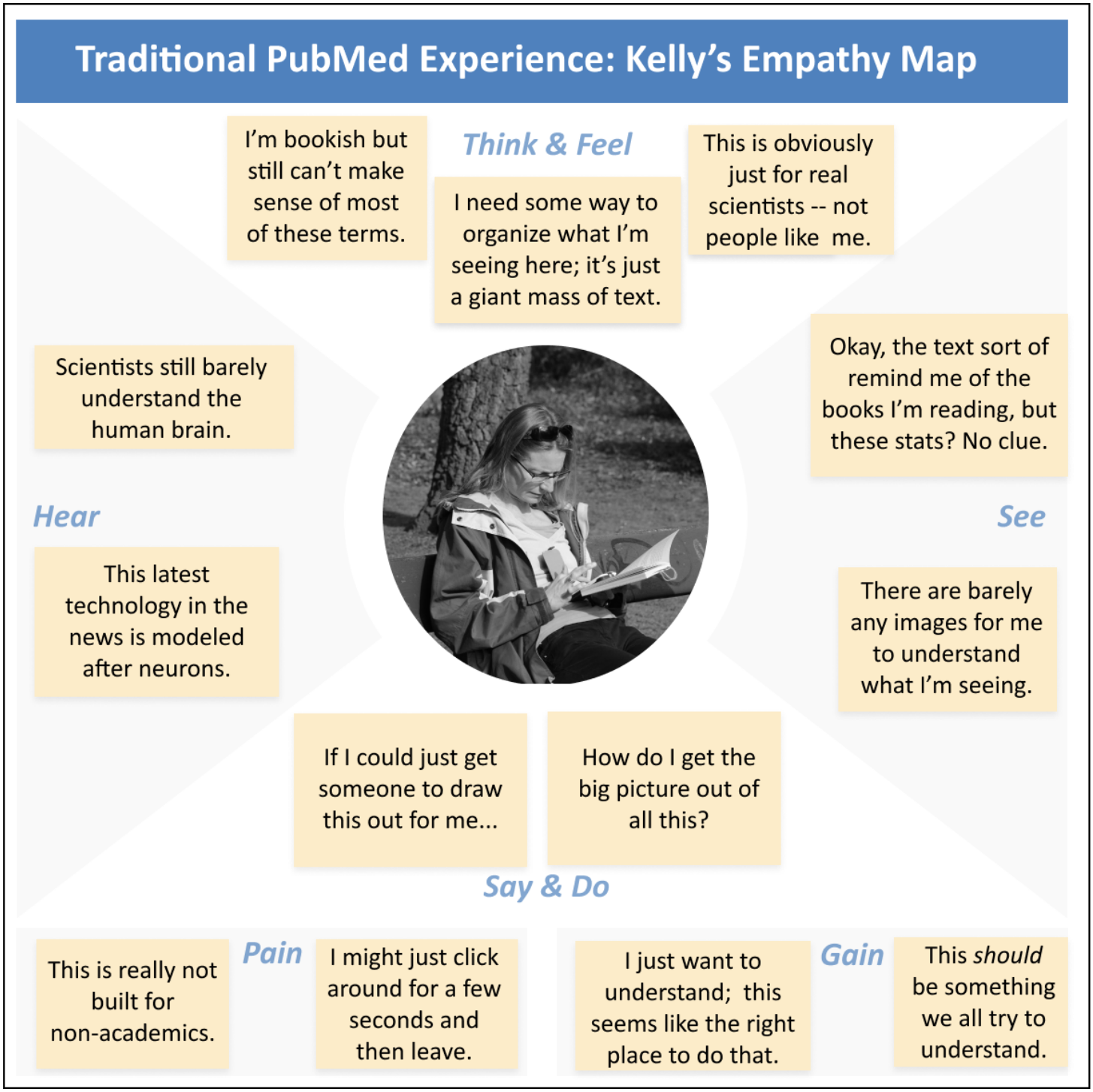
I feel like I'm starting to dig past the surface.

PERSONA #3: KELLY, THE LAYPERSON

NAME
Kelly
AGE
40
GENDER
Female
LOCATION
Philadelphia, PA
OCCUPATION
Artist
EDUCATION
BA in Art History

GOALS AND MOTIVATIONS
Kelly has a few favorite books about pop psychology and neuroscience, like *Blink* by Malcom Gladwell and *Spark* by John Ratey. She has never even heard of PubMed, but as an artist especially, has often wondered, "What does this all even *look* like?" She's seen some visual representations of the brain, but nothing user-friendly enough to interact with herself.

ENVIRONMENT
She has an old MacBook Pro she uses to do some graphic design and her browser of choice is Firefox.
QUOTE
"What does consciousness look like? Is it even possible to know that?"
CREDIT
Image by fsHH from Pixabay



1.5. Elevator Pitch

Online text-based searches of academic databases carry limited dimension by only communicating via the written word. That's why the goal of my capstone is to build an exciting physical interface modeled after the human brain that can act as a search and learning tool connected to PubMed: a free full-text archive of

biomedical and life sciences journal literature. Users will be able to more quickly and easily navigate academic publications on the topic of neuroscience in a demonstrably unique way: visually and spatially. Via a friendly graphic interface and physical computing, studying and exploring the human brain will be an exciting interactive experience.

1.6. Metrics

In order to gauge the success of my capstone project, I've defined five levels of performance:

Level 1:

Minimal Viable Product (MVP) - All technical components are in place and functioning as a cohesive project, though little in the form of creative exploration stands out.

Level 2:

Digital Interactive Art - The frontend and digital 3D model successfully engages the user with appealing visualizations triggered by some physical interaction.

Level 3:

Physical and Digital Interactive Art - The physical 3D model is visually and interactively engaging on its own, in addition to the digital 3D model.

Level 4:

Interactive Art with an Backend-Informed Frontend - The full interactive art piece is supported with a database backend to enhance performance and provide some user guidance on the frontend.

Level 5:

Interactive Art Powered By a Prediction Model - The full interactive art piece includes a dynamic, engaging frontend powered by insights generated by a prediction model.

Feature	Level 1	Level 2	Level 3	Level 4	Level 5
Virtual 3D Model	Basic virtual 3D model of brain mirroring physical 3D model	Visually engaging, attractive, & polished virtual 3D model of the brain with artistic flourishes	Artistically polished, mirroring 3D model, and divided into meaningful regions of interest	Interactive (with mouse), artistically polished, mirroring 3D model, and divided into meaningful regions of interest	Interactive (with mouse and backend data), artistically polished, mirroring 3D model, and divided into meaningful regions of interest

Physical 3D Model	Interactive, 3D-printed representation of brain that triggers input to the web application	Input from the physical model results in interesting and creative visualizations on the virtual model	The physical model itself will have interesting artistic, interactive flourishes (e.g., regions light up) and divided into meaningful regions of interest	The physical model itself will have interesting artistic, interactive flourishes (e.g., regions light up), be divided into meaningful regions of interest, and resemble a finished product	The physical model will have artistic, interactive flourishes, be divided into meaningful regions of interest, and resemble a finished product
Frontend	Form that is populated by physical interactions and controls searches to PubMed	The frontend is well-designed, interesting, and visually cohesive with the virtual 3D model	The frontend is well-designed, informative, and is powered by a cleanly coded component library.	The frontend will dynamically display helpful information generated by the backend in response to input	The frontend will have carefully designed information areas for insights generated by the backend
Backend	*N/A or if needed, barebones routing*	*N/A or if needed, barebones routing*	*N/A or if needed, barebones routing*	A backend exists to save searches and minimal user data to provide some helpful autocomplete functionality	In addition to the backend saving searches and minimal user data, the backend will use a prediction model to generate suggestions for searches.

1.7. Life of the project beyond capstone

I am extremely interested in finding a life for this project beyond my capstone. At minimum, I will reach out to my former mentors in psychology research at Beth Israel Deaconess Medical Center for advice in taking the project further in academic spheres.

I do not have much of a mind for business, but if the prototype works well in an appealing way, I will do some research into VC funding or Kickstarter. It would be worthwhile to explore my connections in academia to gauge interests in co-founding a company, if only to rule it out. I would love to find a way to get the final product in real classrooms without having to start a whole company.

Given the physical interface of the product, I would need to investigate mass-manufacturing or perhaps, a DIY starter kit with pre-fab parts that could easily be put together by a layperson or hobbyist. Alternatively, there may be a way to present the project in a small but public conceptual art venue of some kind. Timing and money not permitting, I would consider publishing writings on Medium.com about the project and open sourcing the code.

It would be a great addition to my portfolio and if anything, a good discussion piece when interviewing for positions outranking my current title of Senior Software Engineer at a health product company.

2. Competitor review

I could not find other non-screen-based interfaces for academic journal databases, nor for the human brain. However, interactive and virtual 3D models are numerous as educational and research applications, including:

BrainFacts.org

Description: BrainFacts.org offers an interactive 3D virtual model in a web-based interface. It allows the user to click on larger regions of the brain, such as the Prefrontal Cortex or the Midbrain, and see a paragraph-length description of the region.

Pros:

- It's a semi-realistic model of the brain with professional-level rendering and lighting.
- It lets you spin the model around (via click-and-drag) and interact.
- It provides a high-level overview of major brain regions in a spatially intuitive environment.

Cons:

- Beyond a paragraph's worth of text per region, it does not offer more information internal or external to the website.
- Though expertly rendered, it does not have any fun flourishes or interactions available.

G2C Brain

Description: G2C Online offers a 3D brain that can be rotated via directional arrow navigation (e.g., up, down, left, right). Hovering provides tooltip labels, but navigation to each region's information is via a dropdown menu.

Pros:

- Much more information is provided than BrainFacts.org, including associated functions, cognitive disorders, substructures, and research citations.
- Unlike BrainFacts.org, regions (or "structures") are color-coded as they are navigated to.

Cons:

- It is a Flash-based website.
- It is dated, particularly its citations: copyrighted 2005-2009.
- Interacting with a region/structure does not result in user navigation (only in labeling).

Allen Brain Map

Description: Multiple projects by the Allen Institute for Brain Science offer comprehensive and highly technical brain atlases of genomic data, many in 3D. Digital graphs and images present where in the brain specific gene expression occurs. Their Brain Explorer desktop application offers a search engine for gene expression locations.

Pros:

- Exhaustive atlases assembled by teams of scientists and millions in funding.
- Specific to gene expression and a database in of itself, which entries linking to external resources like NCBI Entrez Gene.
- Tutorials available on YouTube.

Cons

- Not intellectually accessible to a large audience of anyone without a highly-specialized education in neuroscience and genomics.
- Does not provide high-level overviews (which are, to be fair, not in the scope of these projects).

Competitor Summary

While several similar applications exist for educational and research purposes, none offer non-screen-based user interfaces or provide a breadth of functionality to both specialized and layperson audiences. I was also unable to find alternative user interfaces for academic journal databases. The status quo seems to remain unchallenged as far as textual representation goes.

Comparison Matrix

	BrainFacts.org	**G2C Brain**	**Allen Brain Map**	**PubMed Brain Explorer** *(tentative product title)*
Virtual 3D Brain (Spatial Learning)	✔	✔	✔	✔
Virtual 3D Brain Interactivity	✔		✔	✔
Physical 3D Brain and Interactivity (Kinesthetic and Spatial Learning)				✔
Basic Structural Brain Information	✔	✔		✔
Exhaustive Neuroscientific Search Results			✔	✔
Dynamic, Up-to-Date Data			✔	✔
Intellectually Accessible to General Audience	✔	✔		✔
Useful to Specialized Audience, Researchers			✔	✔

Web-Based, No Downloads Required	✔		✔*	✔
Interactive & Fun Conceptual Art (e.g. entertainment-based responsivity, animations, lights)				✔

*While some Allen Brain Map projects can be accessed online, there is a Brain Explorer that is a desktop-based application that must be downloaded.

3. Technology requirements

Technology #1: 3D Printing

No related coursework or work experience; minimal hobbyist exploration.
Reason: To design a physical model that is 1) divided into meaningful anatomical regions of the brain, 2) compatible with physical computing components, and 3) visually appealing and engaging.
Alternatives: Since the idea is to provide a user interface a step beyond traditional screen-based UIs, alternatives could be virtual reality or augmented reality. Since an augmented reality interface could be anchored to a physical model, creating a physical model as a first step could in fact open the door to that possibility in a later version of this project. Virtual reality simply seems more suitable for immersive environment applications than alternative user interfaces for small objects. No competitors for alternative (non-screen-based) user interfaces for brain models could be found.

Technology #2: Physical Computing: Open-Source Single-Board Computer (SBC) & Touch Sensors

Related Course(s): DGMD E15: "Creative Explorations in Screen-Based and Physical Computing"
Reason: To connect touch sensor input from the physical model to the web application such that specific regions or points of the brain are recognizable to the app.
Alternatives: Tightly coupled with reasoning for 3D printing; see above.

Technology #2: Node.js

Related Work Experience: I have used Node.js on a daily basis as a software engineer for several years.
Reason: To access input data from the physical computing sensors within the embedded linux system of the single-board computer.
Alternatives: The choice of this technology is related to the variety and popularity of open source physical computing libraries available in the Node.js ecosystem for likely SBC candidates (BeagleBone

Black, Arduino, or Raspberry Pi). During actual development, depending on accessories used and software support, it may turn out that a Python library or coding in something like an Arduino IDE is necessary or more suitable. This technology choice is of all technologies, the least set in stone.

Technology #3: Javascript Framework & Visualization Libraries

Related Work Experience: I have used multiple Javascript frameworks on a daily basis for work for years, including React, Ember, Vue, Angular, and more.
Related Course(s): DGMD E15: "Creative Explorations in Screen-Based and Physical Computing", DGMD-E39: "Modular Design Patterns/React", and CSCI E-14A: Building Interactive Web Applications for Data Analysis
Reason: To create a cohesive and visually engaging frontend for the web application that guides the user through the search and exploration of articles and insights.
Alternatives: Javascript is a hard requirement for utilizing WebGL, the Javascript API for rendering 3D. Using lower-level APIs, such as Direct3D, would introduce unnecessary friction in integrating with the rest of the project's language stack and is beyond the scope of this capstone's learning goals.

Technology #4: Backend Python Application & SQL Database

Related Work Experience: I have used Python on a handful of occasions for contract clients as a software engineer. I have frequently used Ruby for backends.
Related Course(s): CSCI E-14A: Building Interactive Web Applications for Data Analysis
Reason: To save search query combinations over time, generate a predictive model for insights based on search results, and use the model to aid the user in academic inquiry and exploration.
Alternatives: A Node.js backend may also be suitable for backend services. In CSCI E-14A, we learned how to build a prediction model using Python libraries and notebooks, then serve predictions from a Django backend. However, this project's stretch goals allow for the exploration of alternative ways to build and serve a prediction model, so Node.js libraries for Tensorflow or cloud-based machine learning services may prove to be more fitting given this project's stack.

4. Visuals describing how your product will be used

General Description

My capstone project is a 3D-printed interactive model of the human brain that controls the navigation of a single-page web application. The product will be a research tool for psychology and neuroscience and an artistic exploration, with a (secondary) long-term potential to also act as a learning tool in classrooms. The web application will react to user interactions with the brain model, mirroring interactions in

easy-to-understand and eye-catching visualizations of the brain on-screen, and triggering searches of PubMed databases.

Stretch Goals: Noteworthy attributes and quantities of search results could stored within a backend database and used to train a prediction model around queries. The model could be used to empower the user with insights as they navigate within the application.

User Journey

Step 1: Visit the web application

A web application will load on a normal web-ready device-- likely a tablet or personal computer. The user won't need to interact with it just yet-- rather, they will be introduced to the physical model and briefly instructed on it's usage. (The physical model will be connected to a single-board computer that serves this web application on a remote server.)

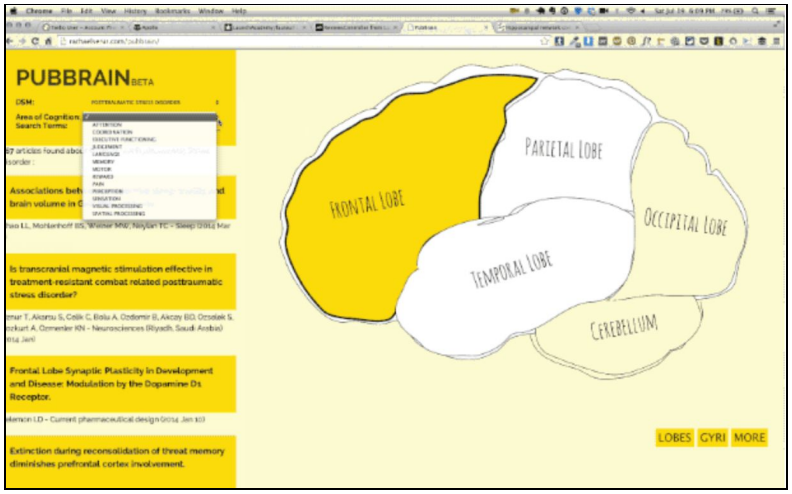


Figure 1. Web Application.

Step 2: Interact with the physical model

After the user has been introduced to the basic usage of the physical model, they will be encouraged to try interacting with the various physical sensors on the brain model right in front of them. As different brain regions are touched, the corresponding areas on-screen will light up, and PubMed database searches will be triggered so that relevant articles are dynamically pulled up.

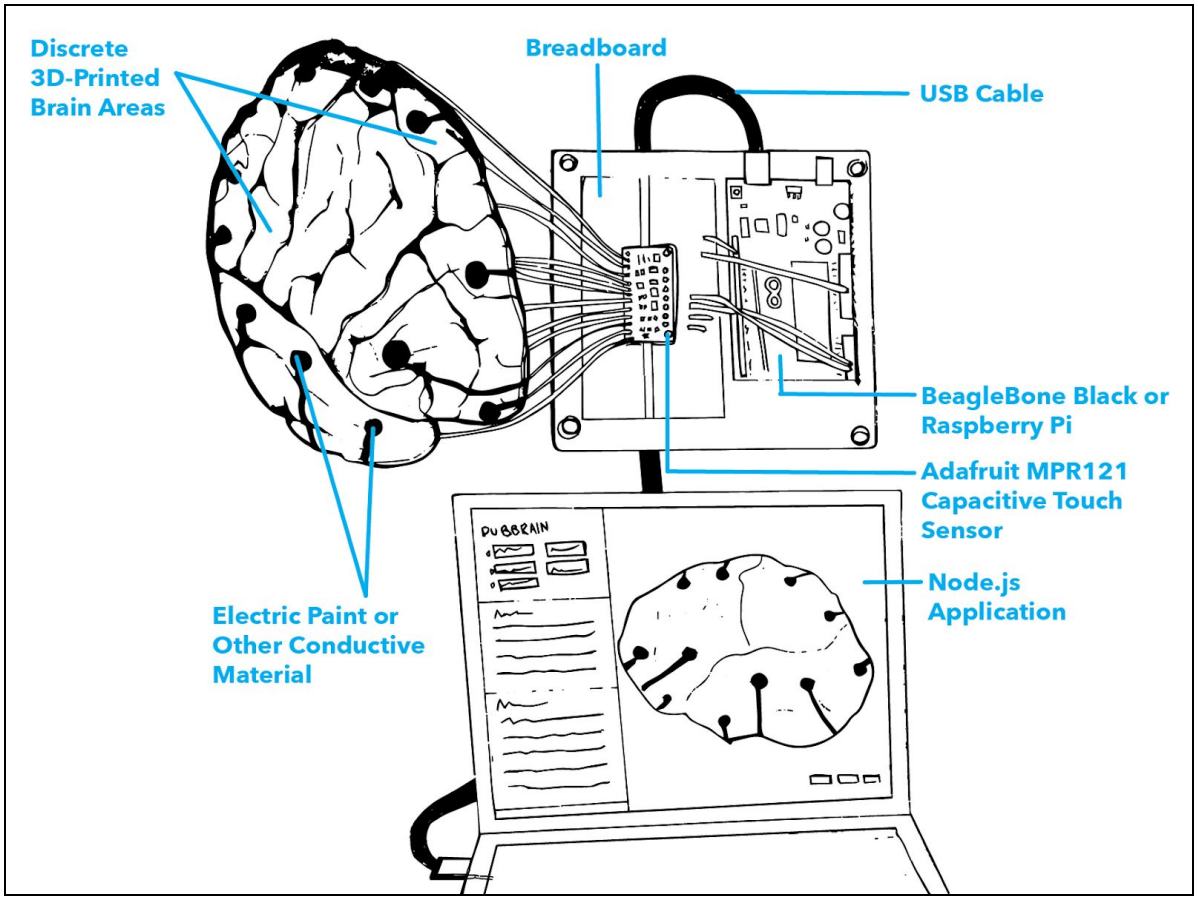


Figure 2. Physical computing elements.

Step 3: Interact with the digital model and search terms

(See Figure 1)

The digital on-screen model (time permitting) will also be interactive. As brain regions are selected, factoids about the region will pop up. Recommended search terms relevant to the brain region will be selectable in additional form fields, such as DSM diagnoses and areas of cognition (like pain, visual processing, reward, etc). As the user manipulates the form, the search results of pubmed articles will dynamically change and resultant articles can be opened up in a new tab or iframe.

5. Work plan and milestones

	TASK TITLE	START	END	DURATION
Phase 1	**Prepare 3D Model**			
1.1	Procure suitable DICOM files from T1-weighted image	8/8/19	8/11/19	3
1.2	Research and define Regions of Interest to highlight with	8/11/19	8/18/19	7

	printed model			
1.3	Use Freesurfer to create surface model + target cortical areas	8/11/19	8/18/19	7
1.4	Use MeshLab or Blender to prepare 3D model for printing and rendering	8/19/19	8/25/19	6
Phase 2	**Build Frontend and Virtual 3D Model**			
2.1	Design and code frontend with React or Vue	8/26/19	9/2/19	6
2.2	Render (virtual) 3D model in frontend and experiment with artistic possibilities in Three.js	9/3/19	9/15/19	12
Phase 3	**Build Physical 3D Model with Sensory Input**			
3.2	Print with low-cost 3D printer or 3D printing service (e.g. ShapeWays)	9/16/19	10/1/19	15
3.3	Compare/experiment with conductive material options: electric paint, filament, foam, or tape?	9/20/19	10/14/19	24
3.4	Connect capacitive touch sensor breakout to conductive brain regions, breadboard, and Single-Board Computer (BeagleBone, Arduino, or Raspberry Pi)	9/20/19	10/20/19	30
3.5	Compare and experiment with JS IoT libraries, e.g. Johnny-Five, Cylon, and Node-RED	9/20/19	10/20/19	30
Phase 4	**Sensory Input Manipulates Web Application**			
4.1	Map raw data to form inputs	10/20/19	10/27/19	7
4.2	Use form inputs to generate PubMed API queries	10/27/19	11/4/19	7
4.3	Reflect sensory input from physical model on virtual model	11/5/19	11/12/19	7
Phase 5	**Backend Database and Prediction Model (Stretch Goal)**			
5.1	Save query parameters and query result counts to backend database	11/12/19	11/19/19	7
5.2	Generate a prediction model for query parameter combinations and result counts	11/20/19	12/15/19	25
5.3	Use prediction model to generate search recommendations for frontend	12/9/19	12/19/19	10

GANTT Chart (Grouped by Phase) - Click for Full Chart

#	TASK TITLE	START	DUE	DAYS
1	**Prepare 3D Model**			
1.1	Procure suitable DICOM files from T1-weighted image	8/8/19	8/11/19	3
1.2	Research and define Regions of Interest to highlight with printed model	8/11/19	8/18/19	7
1.3	Use Freesurfer to create surface model + target cortical areas	8/11/19	8/18/19	7
1.4	Use MeshLab or Blender to prepare 3D model for printing and rendering	8/19/19	8/25/19	6

#	TASK TITLE	START	DUE	DAYS
2	**Build Frontend and Virtual 3D Model**			
2.1	Design and code frontend with React or Vue	8/26/19	9/2/19	6
2.2	Render (virtual) 3D model in frontend and experiment with artistic possibilities in Three.js	9/3/19	9/15/19	12

#	TASK TITLE	START	DUE	DAYS
3	**Build Physical 3D Model with Sensory Input**			
3.1	Print with low-cost 3D printer or 3D printing service (e.g. ShapeWays)	9/16/19	10/1/19	15
3.2	Compare/experiment with	9/20/19	10/1	24

	conductive material options: electric paint, filament, foam, or tape?		4/19		
3.3	Connect capacitive touch sensor breakout to conductive brain regions, breadboard, and Single-Board Computer (BeagleBone, Arduino, or Raspberry Pi)	9/20/19	10/20/19	30	
3.4	Compare and experiment with JS IoT libraries, e.g. Johnny-Five, Cylon, and Node-RED	9/20/19	10/20/19	30	

#	TASK TITLE	START DATE	DUE DATE	DAYS
4	**Sensory Input Manipulates Web Application**			
4.1	Map raw data to form inputs	10/20/19	10/27/19	7
4.2	Use form inputs to generate PubMed API queries	10/27/19	11/4/19	7
4.3	Reflect sensory input from physical model on virtual model	11/5/19	11/12/19	7

PHASE FOUR

WEEK 11							WEEK 12							WEEK 13						
M	T	W	R	F	S	S	M	T	W	R	F	S	S	M	T	W	R	F	S	S

#	TASK TITLE	START	DUE	DAYS
5	**Backend Database and Prediction Model (Stretch Goal)**			
5.1	Save query parameters and query result counts to backend database	11/12/19	11/19/19	7
5.2	Generate a prediction model for query parameter combinations and result counts	11/20/19	12/15/19	25
5.3	Use prediction model to generate search recommendations for frontend	12/9/19	12/19/19	10

PHASE FIVE

WEEK 14							WEEK 15							WEEK 16							WEEK 17							WEEK 18						
M	T	W	R	F	S	S	M	T	W	R	F	S	S	M	T	W	R	F	S	S	M	T	W	R	F	S	S	M	T	W	R	F	S	S

Milestones and Deliverables

Milestone #1: 3D Model of the Human Brain (Files)

Date: August 25th, 2019
Deliverables: Clean 3D models well-prepared for 3D printing, as well as web rendering, that represent a careful selection of significant regions of interest.

Milestone #2: Skeletal Frontend and Virtual 3D Model

Date: September 15th, 2019
Deliverables: A well-designed React or Vue frontend (not yet interactive) that creatively displays a virtual 3D model of the brain.

Milestone #3: Physical 3D Model with Sensory Inputs

Date: October 20th, 2019
Deliverables: The 3D-printed model with working sensory inputs to a Single-Board Computer (SBC).

Milestone #4: Web Application

Date: November 12th, 2019
Deliverables: A functioning web application that takes in sensory input, reflects interaction on a virtual 3D model, and uses input to generate PubMed API queries.

Milestone #5: Backend database and prediction model (Stretch Goal)

Date: December 20th, 2019
Deliverables: A backend database that saves query parameters, a prediction model for result counts based on query parameter combinations, and resulting search recommendations presented to the frontend.

6. References

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