Developing a Web-Based Neurotechnology Standards Dashboard

October 12, 2023

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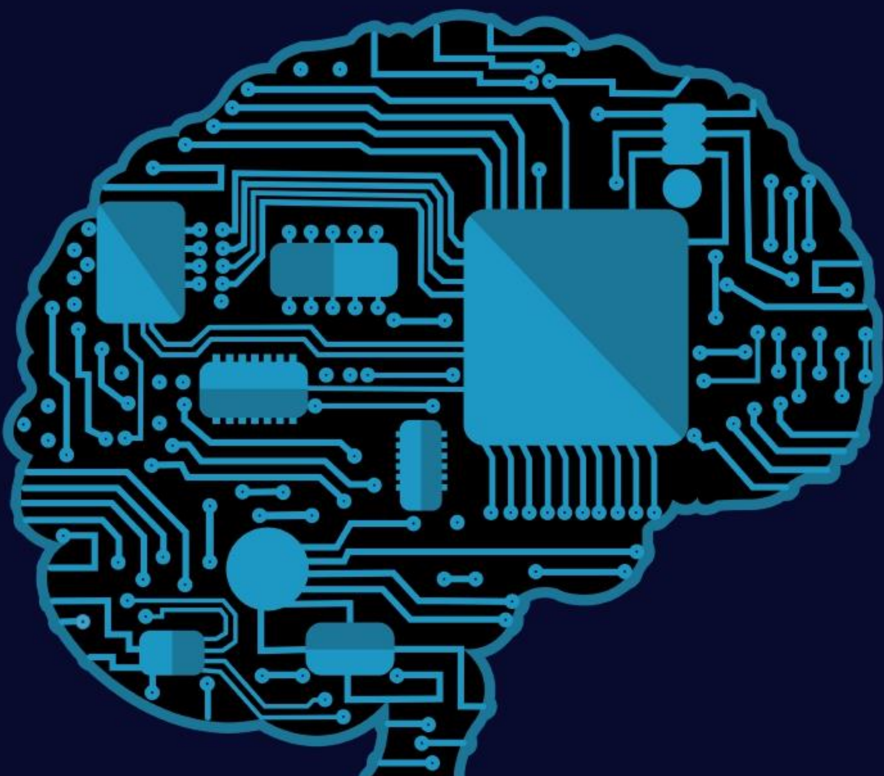

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Developing a Web-Based Neurotechnology Standards Dashboard

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Abstract

Neurotechnology standards help foster ethical developments by professionals in the field, but accessing them can be complicated. We, alongside Dr. Ricardo Chavarriaga of the Zurich University of Applied Sciences, aimed to consolidate existing standards into a novel dashboard and updatable database where professionals can better access these resources. To develop the dashboard, we familiarized ourselves with how professionals interact with standards, curated documents for database inclusion, and constructed a working product. The dashboard streamlines the process of accessing standards. Future expansions should improve technical features, develop a document curation process, and build inter-organizational support for this impactful tool.

Executive Summary

Standards are established by Standards Development Organizations (SDOs) across scientific fields to encourage new inventions and consistency in development processes and procedures. Utilization of these standards guides the dissemination of new technologies within a field (Baron & Kanevskaia, 2023), ultimately upholding innovation within the field. Neuroscience is not a new field, but in recent decades, neurotechnology experts have been developing devices that can both “record and stimulate electrical activity in the nervous system” (Cometa et al., 2022), and SDOs are working to standardize terms and processes within this developing realm (IEEE SA Industry Connections meeting connections, personal communication, September 28th, 2023). With a variety of documents coming out of SDOs, some researchers, clinicians, and industry developers look toward existing documentation to inform the creation of novel processes and devices. As per the eighth recommendation of the Institute of Electrical and Electronics Engineers (IEEE) Standards Association Industry Connections’ (SA IC) *Standards Roadmap: Neurotechnologies for Brain-Machine Interfacing* (BMI Standards Roadmap, 2020), due to the uncertainty of developments in neurotechnology, the ability to easily update standards must be achieved. Our solution to this problem is a novel web-based dashboard that can readily store, update, and search for standards. It should be noted that this problem is not exclusive to neurotechnology. Taking this into consideration, we built our dashboard in a way that it can be easily adapted to other scientific fields to address this issue.

Neurotechnology Background

Neurotechnology is a field of science that encompasses all technologies interacting with the brain and its functions, whether simply monitoring neural activity or actively repairing and improving cognitive functions. Neurotechnological devices have already seen applications in treating neurological diseases, such as improving mobility in persons with movement disabilities. Although neurotechnology has been utilized primarily in the medical field, it has an expanding sector in commercial products, potentially integrating into everyday life.

Our project focused primarily on one of the field's most innovative types of research, namely brain-computer interfaces (BCIs). BCIs are sophisticated systems that capture and interpret brain activity data, processing it via computers to generate internal effects through electrical stimulation or external commands to control physical devices. The vast potential of BCIs is propelled by ongoing improvements in sensing technology, reliability, and signal-processing techniques (Shih et al., 2012).

Methodology

To create an accessible product that meets the needs of researchers, developers, and medical clinicians, we followed three main objectives:

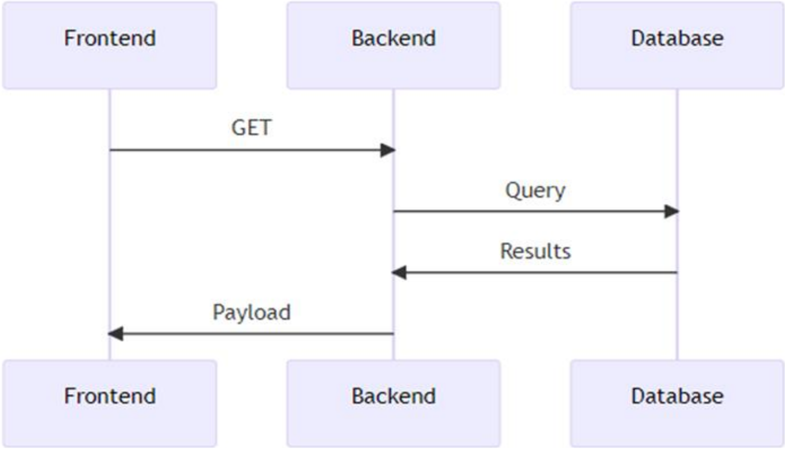
1. familiarized ourselves with the complex field of neurotechnology through intensive research of the problem space and interviews conducted with industry professionals
2. surveyed existing documents from various organizations and explored ways to categorize them for submission in our accessible database
3. developed a web-based dashboard that effectively searches a resource-rich database which allows for future teams to build upon it in future adaptations of this project

Our research into the problem space provided enough information to identify the needs of our stakeholders: researchers, clinicians, and industry developers. We prototyped the dashboard and, using our stakeholder profiles, interviewed individuals whose insight helped us refine the user experience. To populate the dashboard's database, we found and categorized standards, guidelines, and journal articles relating to neurotechnology. The sample we collected was limited in quantity by the project scope but was representative of a complete collection of relevant resources. We utilized open-source tools to build the dashboard to ensure it could be easily expanded upon and improve trust in the technical product. With a minimum viable product (MVP) finished, we presented and demonstrated its functionality to a focus group of industry professionals to gain valuable feedback to guide future iterations.

Results

In five weeks of development, we constructed a full-stack functioning neurotechnology standards dashboard, which we coined NeuroDash. A comprehensive video demonstration of the dashboard's functionality can be found at https://youtu.be/lU2cym2oB5w.

Figure ES1. Software Stack Diagram



Note. The framework for the dashboard and how the frontend, backend, and database interact with each other.

The dashboard has a frontend interface allowing users to interact with a database that stores over 50 categorized standards. Users can use a simple (see Figure 2) or advanced search bar to find the resources they need. When executing a search, the identified keywords and filters are processed by the backend of the website, and the most relevant results are returned on a highly interactive results page (see Figure 3). This technical flow can be seen in Figure 1. Users can learn more about individual results from the results page by clicking on the document's title or the URL that takes them directly to the website that houses the document. Clicking on the title of the document takes the user to a summary page containing the URL to the document’s original website, as well as other information such as the Standard ID, the DOI, the authorship, the date of publication, a list of the categories that we assigned to it, and the publicly available abstract. We do not claim ownership of the documents on our website, as only links to the resources are included instead of actual files. We ensured that every aspect of the dashboard was developed with meticulous documentation to encourage further developments by future teams.

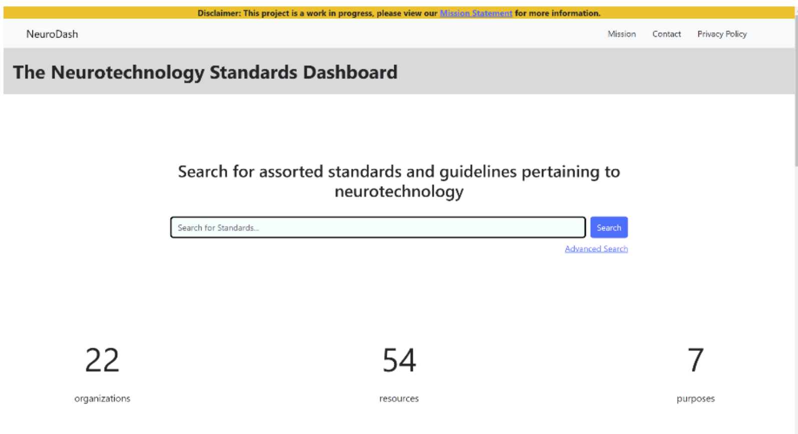


Figure ES2. NeuroDash Home Page

Note. The front page of the dashboard displays the search bar and resource statistics.

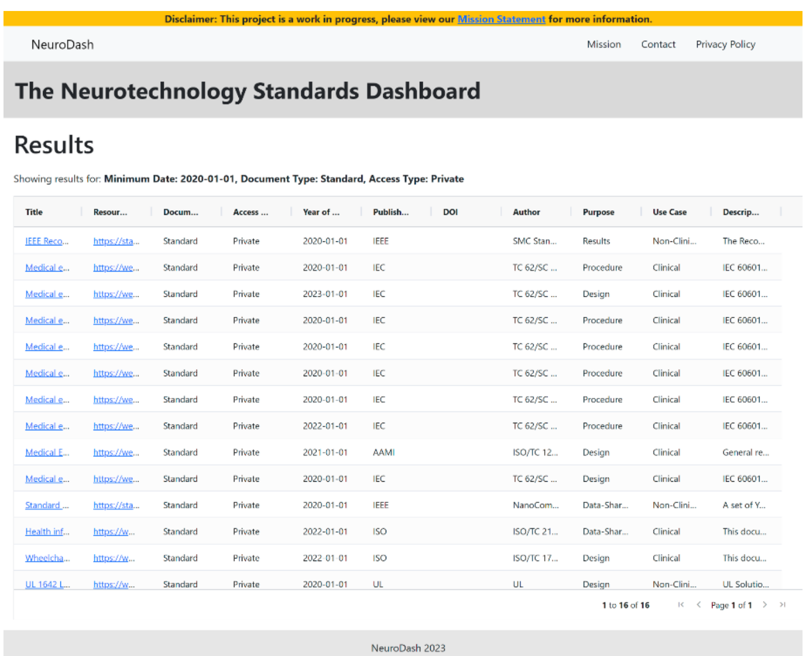


Figure ES3. NeuroDash Results Page

Note. The results page shows the user’s query and a set of results matching that query.

We had the opportunity to demonstrate the dashboard directly to the IEEE SA Industry Connections group focusing on Neurotechnologies For Brain-Machine Interfacing. After our presentation and a short demonstration of the website's functionality, we received positive feedback and suggestions on areas to change and improve upon. Multiple group members openly expressed their support for our work and assured us that they would continue sharing our project with their colleagues to gain more interest.

Conclusions and Recommendations

The version of the dashboard we created focused heavily on meeting the requirements of a MVP, a functional product able to be demonstrated to potential users. However, further work is needed to reach the point where professional stakeholders can trust and utilize our dashboard. We identified three primary areas for future expansions:

1. Development — Advancing technical features and aspects of the dashboard
2. Curation — Improving the methods for the collection and categorization of resources
3. Support — Building awareness and publicity between organizations and individuals

Development

The feedback we received through interviews and our focus group identified multiple technical steps we recommend taking to improve the dashboard. Some of these include:

- Integrating Natural Language Processing (NLP) to improve the accuracy of the search function
- Implementing user accounts for more personalized experiences and uploading and suggesting documents
- Exploring the utilization of the IEEE SA OPEN platform, an open-source development resource (IEEE SA OPEN. n.d.), to host the website

Making the dashboard code open-source will allow the neurotechnology community to make changes and improvements to NeuroDash. Software that takes an open-source approach to its development are characteristically more transparent and often foster a greater sense of community than its proprietary alternatives (von Krogh & Spaeth, 2007).

Curation

The current collection of documents in NeuroDash is a representative sample of available neurotechnology standards, articles, and other resources that stakeholders need to access. To improve the process of curating resources for inclusion in the database we recommend to:

- Directly involve those who are most knowledgeable in the field in the selection and categorization process of documents uploaded to NeuroDash

- Include community feedback on documents to help limit the impact of document bias by allowing users to note the utility of a document through a vote, comment, or other metric

Support

Support from multiple organizations and individuals in the neurotechnology field is the most influential factor for the project's success. Our team's presentation to the IEEE SA IC group was the first step in building project awareness. Continued growth of the project should:

- Seek support from primary actors associated with SDOs
- Not affiliate the project efforts with a single organization; it should instead be a product of the collaboration of multiple organizations
- Build awareness and promote adoption of the dashboard in our primary stakeholder groups

Without the neurotechnology community's support, this project will struggle to be further developed or adopted.

Closing Thoughts

Our implementation of a standards dashboard provides a robust technical baseline to address the need for standards to be centralized and easily updatable. Standards play a crucial role in promoting developments made in the field, but without accessibility, they are underutilized. The web-based standards dashboard is a unique approach to this problem and feedback from professionals suggests that it is an effective solution. The dashboard framework has the potential to be taken beyond the field of neurotechnology, and implementing our solution across other scientific fields could solve the common issues associated with the utilization of standards. The development of NeuroDash amplifies the benefits of standards, encouraging and upholding innovation in the neurotechnology community. Responsible innovations in the field directly benefit clinical practices, medical research, device development and the in-field use of the technology. The effects of responsible innovations directly impact the quality of life of the commercial and medical end users of technologies created by researchers, clinicians, and industry developers.

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Authorship and AI Disclaimer

This report results from a highly collaborative effort between all team members. However, the writing was divided amongst team members to ensure an even workload. All sections were edited and approved by all team members. The primary authors of each chapter are listed here. Max and Cutter wrote the abstract. The executive summary was written by everyone, following the same writing layout as the main chapters as outlined below. Chapter 1, Introduction, was written by Cutter and Eric. Chapter 2, Background, was written by everyone. Lucca wrote sections 2.1 through 2.4, Max wrote section 2.5, Eric wrote section 2.6, Cutter wrote 2.7, and Eric and Cutter wrote section 2.8. Chapter 3, Methodology, was written by Lucca and Eric. Chapter 4, Results, was written by Eric, Max, and Cutter. Finally, Chapter 5, was written by Max and Lucca.

This work is original to the project authors and study participants and was not generated or assisted using ChatGPT or any other AI tools.

Meet the Team

NeuroDash Team, from left to right: Eric Whitty, Cutter Beck, Maxwell Jacobson, Lucca Chantre

Cutter Beck: I am a junior from Charlton, Massachusetts studying Computer Science and pursuing an Astrophysics concentration. Switzerland's gorgeous landscape offered unbelievable sights, like the peak of the Matterhorn from a glacier. Working with the CAI at ZHAW was a great experience, and I plan to stay in contact with the amazing people there!

Lucca Chantre: I am a third year majoring in computer science at WPI with a minor in music. I am from Waltham, Massachusetts. I enjoyed my time in Switzerland, working at ZHAW and seeing the country on the weekends. My favorite memory was when I went to a jazz club in Bern and got a chance to play piano in a jam session with some of the locals.

Max Jacobson: Hello! I am a Junior Aerospace Engineering student with a focus in Astronautics from Denver, Colorado. Working on such an engaging project has been such an amazing opportunity. It was incredible experience working with the people at ZHAW. In between working on the project, I have loved exploring Switzerland's amazing cities, mountains and lakes.

Eric Whitty: Hello! My name is Eric Whitty and I am a Junior Biomedical and Mechanical Engineering double major from Methuen, Massachusetts. I've had an incredible time completing my IQP here in Switzerland surrounded by the amazing Swiss Alps, bustling cities, and beautiful nature. The experiences I have gotten through my time here at ZHAW will definitely remain significant to me throughout my life.

Acknowledgments

Throughout the entirety of our project process, our advisors, Dr. Uma Kumar and Dr. Leonard Polizzotto, provided us with valuable insights and guidance that led to our overall success, and for that, we thank them immensely. We thank the five other Switzerland 2023 project groups for providing us with feedback, which was invaluable to our ability to present and explain our project. Without the hard work of our Project Center Director, Dr. Nancy Burnham, arranging this project opportunity behind the scenes, we would not have had the chance to create a tool to better our society in the future and see the beautiful country of Switzerland. Finally, we would like to express our sincerest gratitude to Dr. Ricardo Chavarriaga and the Zurich University of Applied Sciences for sponsoring our team's project, being incredible hosts, and providing us with the opportunity to develop a product that has a bright future for growth and use in the field of neurotechnology.

Chapter 1. Introduction

Standards are established by Standards Development Organizations (SDOs) across scientific fields to encourage new inventions and consistency in development processes and procedures. Utilization of these standards guides the dissemination of new technologies within a field (Baron & Kanevskaia, 2023), ultimately upholding innovation within the field. Neuroscience is not a new field, but in recent decades, neurotechnology experts have been developing devices that can both “record and stimulate electrical activity in the nervous system” (Cometa et al., 2022), and SDOs are working to standardize terms and processes within this developing realm (IEEE SA Industry Connections meeting connections, personal communication, September 28th, 2023). With a variety of documents coming out of SDOs, some researchers, clinicians, and industry developers look toward existing documentation to inform the creation of novel processes and devices. As per the eighth recommendation of the Institute of Electrical and Electronics Engineers (IEEE) Standards Association Industry Connections’ (SA IC) *Standards Roadmap: Neurotechnologies for Brain-Machine Interfacing* (BMI Standards Roadmap, 2020), due to the uncertainty of developments in neurotechnology, the ability to easily update standards must be achieved. Our solution to this problem is a novel web-based dashboard that can readily store, update, and search for standards. It should be noted that this problem is not exclusive to neurotechnology. Taking this into consideration, we built our dashboard in a way that it can be easily adapted to other scientific fields to address this issue.

Brain-computer interfaces (BCIs), an overarching term for technology that reads from or communicates with the brain, have been developed quickly over the last decade to treat disorders of consciousness (Lewis et al., 2023), Alzheimer’s disease, and mobility disorders (Warwick, 2018). They have also become consumer devices marketed for fun and productivity (Neurosity, 2023). This close interaction with the human brain draws critical ethical concerns. Researchers, clinicians, and industry developers work together to define and update approved methodologies to ensure safety and interoperability when creating new technologies.

Our sponsor university, the Zurich University of Applied Sciences (ZHAW), and its Centre for Artificial Intelligence (CAI) work closely to monitor developments in neurotechnology research (ZHAW Zurich University of Applied Sciences, n.d.-a). The head of the CAI, Dr. Thilo Stadelmann (ZHAW Zurich University of Applied Sciences, n.d.-b), and research associate, Dr. Ricardo Chavarriaga (ZHAW Zurich University of Applied Sciences, n.d.-a), are our key contacts at the CAI.

Rapid development within neurotechnology has created a divide between research and the standards that guide it. Dr. Chavarriaga has sponsored this collaborative effort to create a tool that will allow researchers, clinicians, and industry developers an efficient process to find and keep up to date with new standards. Enhancing the culture of collaboration and sharing data will encourage advancements in this field, too. Three objectives guided our progress toward this goal. The first objective was to understand the state of the complex field of neurotechnology by researching the problem space and interviewing industry professionals. The initial research helped us better understand the utilization of standards and guidelines. The second objective was to survey existing standard documents from various organizations such as the IEEE SA and the ISO and explore ways to categorize them for submission in our database. Our final objective and project deliverable was to develop a web-based dashboard that efficiently searches for documents within the database. The dashboard presents statistics on the origins of documents within the database to enhance the credibility of our product. This dashboard will streamline the research process for numerous stakeholders and enhance the outcomes of device creation, patient treatment, and consumer use of neurotechnology products.

Following this introduction are the background, methodology, results, and conclusion chapters. The background will cover the concept of neurotechnology concerning current devices, their current and future applications and concerns, and the ethicality of such research. The background chapter provides the necessary context to understand why this project benefits the field and the reasoning for the steps taken in our methodology chapter. The methodology chapter discusses and connects the selected research methods to our project goal and objectives. The results chapter will go in-depth into the development process of the dashboard as well as user feedback on our design. A conclusion will specify the United Nations' Sustainable Development Goals (SDGs) our project targeted.

Chapter 2. Background

Without the ease of access to new standards in the rapidly evolving space of neurotechnology, researchers, clinicians, and industry developers risk falling behind in providing trial subjects or other experiments with the highest possible care set by professionals worldwide. In this chapter, we explore the complexities of neurotechnology and those invested in it to explain our problem space. After presenting our sponsors and those whom this project will benefit most, we discuss a brief history of state-of-the-art neurotechnology and its future trajectory regarding devices, applications, and guiding standards. We conclude with two case studies to highlight lessons that embody the relevance of our deliverable in this space and the necessity it holds for those creating and receiving neurotechnological devices and procedures.

2.1 What is Neurotechnology?

The dream of interfacing the human brain with technology previously belonged exclusively to science fiction. However, developments and breakthroughs in the rapidly growing field of neurotechnology have brought this prospect closer to reality than ever (Precedence Research, 2022). Neurotechnology is a field of science that brings the vision of connecting the human body with technology to life. It draws upon expertise from diverse scientific fields to develop complex systems that vastly improve the user's experience and advance our understanding of the human brain. The range of applications for these devices is expansive. Neurotechnological devices have already seen applications in treating and diagnosing neurological diseases and have also been found to enhance the function of persons with movement and communication disabilities (Rodriguez-Oroz et al., 2005; Warwick, 2018). Along with medical applications, the use of neurotechnology is expected to see massive growth in the industries of entertainment (Keebler et al., 2012), warfare (Ienca et al., 2018), and artificial intelligence (AI) systems (Fiani et al., 2021).

Since neurotechnology interfaces directly with the nervous system, it is important to understand the role that the nervous system plays in the human body. The nervous system, consisting of the spinal cord, brain, and an expansive full-body nerve network, processes information and coordinates activity throughout the body by sending and receiving electric signals. Functions such as cognition, language processing, and motor control are all associated with the nervous system. Advanced sensing technologies can detect and record electrical signals within areas of the nervous system to interpret and analyze behaviors and actions. Not only can devices sense activity, but they have the potential to modulate the nervous system's activity (Sui et al., 2022). Understanding the powerful potential of neurotechnology has encouraged organizations to work toward prioritizing responsible development in the field.

2.2 What are Standards?

To introduce the concept of standards, we will utilize a simple example. Two teams of researchers are looking to create a new invasive BCI to help treat a specific disorder. The first research team starts the development by creating their device independently. Their study produces intriguing results, and the second team wants to confirm the first team's findings. The data the first team recorded is sent to the other group. The experimentation techniques and data structure used by the first team are novel, and the second team does not know how to interpret them. The first team chose to conduct their experiment in a way that made sense to them, but to the other team, there was no way to decipher the results without thoroughly communicating with the first team. The first team's results may be difficult to validate or replicate without understanding the process undertaken to gain results. This situation is avoidable if both teams agree on certain conventions and practices before experimentation. With the agreed-upon conventions published for the public to see, the results of any experimentation done in this area can be understood and replicated with relative ease.

Standards are essential to collaboration; they allow information and practices to be standardized and interpretable from team to team and industry to industry. Standards "establish consistent protocols that can be understood, adopted, and improved upon" by various individuals and teams (IEEE SA, 2021). Standards are created by committees and working groups consisting of industry professionals, researchers, and regulators (Baron & Kanevskaia, 2023). Standards documents are published by various organizations with varying levels of specificity. Some documents may relate to patient privacy practices in the medical field, while others may describe the requirements of disposable electrodes used in electrocardiograms. (ANSI/AAMI, 2015).

2.3 Stakeholders

We recognize the wide-reaching number of possible stakeholders in the field of neurotechnology, but under the guidance of our sponsor, we have limited the initial stakeholder consideration to three groups for this phase of the project: researchers, clinicians, and industry developers. Each of these three groups needs to work together to ensure that developments in the field are beneficial for all. Standards encourage safe practices within studies and the use of similar methods in different labs. As interest in neurotechnology expands to numerous labs in various countries, discrepancies in research will occur, and access to these standards will allow for productive communication of results and keep researchers on track for ethical advancement.

2.4 Project Sponsors

This project is only possible due to the generosity and help of the sponsor, the Zurich University of Applied Sciences (ZHAW). The ZHAW is one of the premier universities for applied sciences in Switzerland, consisting of schools for engineering, management, health sciences, and more. Our project collaborates with the ZHAW School of Engineering and the ZHAW Centre for Artificial Intelligence (CAI). Created in 2021, the CAI is an organization at ZHAW that specializes in AI developments and applications (ZHAW School of Engineering, n.d.). Dr. Thilo Stadelmann is head of the CAI and seeks to educate students and experts on state-of-the-art AI research while emphasizing the societal implications of new technologies (ZHAW School of Engineering, n.d.).

One of our two primary contacts is Dr. Thilo Stadelmann, a professor at ZHAW, who boasts an impressive background in computer science. Much of his research is focused on AI systems and machine learning. At ZHAW, he teaches computer science in the School of Engineering and is head of the CAI. He is a well-known expert in AI and machine learning, focusing heavily on exploring the ethical implications of these technologies (ZHAW Zurich University of Applied Sciences, n.d.-b).

Our other primary contact is Dr. Ricardo Chavarriaga, a senior research associate at ZHAW who has been studying computational neuroscience for over twenty years. He chairs numerous neurotechnology standards boards such as the IEEE SA IC, and through this group he collaborated with other field experts to author a standards roadmap that reviews existing and developing standards in neurotechnology and brain-machine interfacing. He has noted that this roadmap went out of date not long after it was published, so he seeks to create a tool where researchers, regulatory bodies, and ethics compliance specialists can find up-to-date information in one place (ZHAW Zurich University of Applied Sciences, n.d.-a).

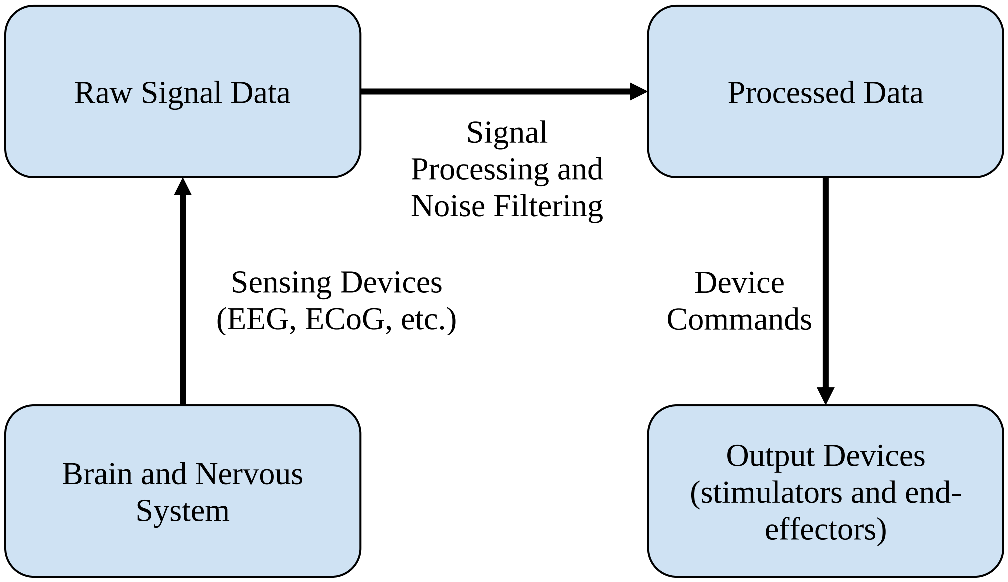
2.5 State-of-the-Art Neurotechnology

2.5.1 Defining Brain-Computer Interfaces

Neurotechnology is a broad field, which includes many types of devices and systems that each have unique methods of interfacing with the human nervous system. Some of the most promising types of devices are brain-computer interfaces (BCIs). These devices are characterized by their direct interaction with the human brain and their three-step process. These steps can be seen in Figure 1. First, the device captures and records signals directly from the brain using a wide variety of types of sensing equipment. Next, this information is processed using advanced computing and signal processing techniques and then translated into commands readable by output devices. These output devices either directly give feedback to the brain or interface with the environment around the user (Shih et al., 2012).

Figure 1. BCI System

The components of a BCI system highlight the sensing, processing, and outputting processes.



2.5.2 Processes of Brain-Computer Interfaces

Sensing and processing are key components of BCI systems. To extract data, specialized sensing devices designed to capture information from the electrical activity in the brain are used. These sensing devices can either be non-invasive, often wearable in the form of headsets, or invasive, requiring surgical insertion directly into the brain. One of the most common methods of non-invasive sensing is an electroencephalogram (EEG). These EEG devices utilize electrodes placed on the user's scalp to read electrical signals from the brain (Shih et al., 2012). Alternatively, electrocorticography (ECoG) devices utilize direct contact with neurons in the brain to record their activity (Caldwell et al., 2019). The different sensing systems have many advantages and drawbacks, and each has unique applications. Once the data is collected, it must be processed into meaningful information. The electrical data must be passed through advanced filters to eliminate noise and then be translated into digital data. This data is often analyzed using complex algorithms and advanced AI technology, such as neural networks and machine learning (Elmalaki et al., 2021). What happens next to the processed data depends entirely on the device's intended purpose.

Given their nature as highly specialized devices, BCIs are designed with clear goals to address unique problems effectively. Brain-computer interface systems can be roughly categorized by their output type. Some are developed with the intention of assisting the user in interacting with their external environment, sending commands to physical hardware. This hardware ranges from motorized prosthetics and mobility aids to communication supports (Shih et al., 2012). Other BCIs are targeted toward modulating the brain's internal environment. This can be done through direct stimulation techniques, which allow for the treatment of neurological disorders and psychiatric illnesses (Caldwell et al., 2019). Brain-computer interfaces have seen immense success in their current implementations, and the prospects of further developments are encouraging.

2.5.3 Current Uses for Brain-Computer Interfaces

Many examples of successfully implemented BMIs have been seen primarily in medical applications. Conducting a study using BCI technology, Willet et al. successfully developed a method of converting brain signals into text-based communications (2021). Researchers were able to convert detected signals into digital text with high success rates using intracortical electrodes to sense brain activity associated with handwriting letters. Researchers achieved results comparable to the average person's texting speed by utilizing advanced data processing and supporting trained language models. Geared toward people suffering from degrees of paralysis, BCIs were proven to drastically enhance the user's ability to communicate in a way previously unobtainable without neurotechnology (Willett et al., 2021).

Deep brain-machine interfaces (DBMI) use analyzed data to stimulate the human brain, and they have proven highly effective in treating Parkinson’s disease (Sui et al., 2022). Classified as a neurodegenerative disorder, Parkinson’s disease involves the degradation of areas in the brain tasked with motor control (Groiss et al., 2009). Deep brain stimulation (DBS), controlled by information collected from implanted electrodes and directed at these motor control areas, saw significant improvements with relatively minimal side effects in patients suffering from more advanced stages of the disease (Sui et al., 2022). The power of BCI devices is evident in their success in medical applications in treating health conditions and enhancing user experiences.

Not all use cases for BCIs are in the medical field, however. The consumer neurotechnology market is expected to be valued at $38.17 billion by 2032, reaching $14.3 billion by the end of 2023 (Precedence Research, 2022, para. 1). Companies are making non-invasive technologies with reasonable price tags targeted at consumers today. One of these devices is the Crown by Neurosity. The Crown claims to help the wearer concentrate better while working through music and other feedback based on the user's EEG readings (Neurosity, 2023). The Crown also offers a companion software development kit that allows owners to independently develop programs that directly incorporate the EEG data from the wearable device (Neurosity, 2023).

2.6 Neuroethics

2.6.1 Defining Neuroethics

Within neurotechnology lies an interdisciplinary field: neuroethics. Neuroethics focuses on defining the ethical issues of advancing neurotechnology and the implications of influencing and monitoring the brain (Roskies, 2021). Conflicting views arise with respect to prioritizing, accommodating, and adjusting to a wide variety of principles and morals held by society. When weighing these views against each other, one must inspect each side's intentions, moral judgment, regard for health and well-being, and classification of right and wrong (Keebler et al., 2012).

During our project, we had the opportunity to tour the Lausanne University Hospital (CHUV) and their Department of Clinical Neuroscience, where they have a group focusing specifically on neurorehabilitation for disorders of consciousness. According to the department, the uncertainty within this line of work lies in a professional's ability to diagnose coma patients accurately. A coma can be described as a vegetative state where the patient is unresponsive, and their eyes are closed. While professionals have made remarkable developments with respect to diagnosing this complicated condition, new questions arise regarding the accuracy of these methods. It is estimated that roughly 40% of patients identified with a traumatic brain injury are wrongly diagnosed as vegetative (Schackners et al., 2009). Recoverability was commonly noted through open eyes, improving motor functions, and verbal response. Through our tour of CHUV and its Clinical Neuroscience department, we discovered that the signs and speed of recovery vary by patient and are often unclear. Many of these patients can recover with extensive neurorehabilitation but are instead denied due to a misdiagnosis.

2.6.2 Implications

As typical in other medical practices, neuroethics has many implications. An implication is a potential future consequence and could be characterized as neurotechnology research's impact on society, whether positive, negative, or negligible. Importantly, one should note that these implications may not immediately or directly impact the field but will influence its social or economic standing. To better understand the implications of neurotechnology, archetypes will need to be presented. Although the neurological agent at work in this example is a drug and not a technological device, Farah (2005), in "Neuroethics: The Practical and the Philosophical," asks if people can take credit for work done on prescription stimulants or if it should be considered a bodily enhancement that cheats others out of the same productivity boost. In the past, bodily enhancement would not have been a significant concern, but with advancing neurotechnology, the boundaries are pushed further from what was thought possible. Likewise, neurotechnology pushes the bounds of privacy. Studies have been done on using neuroimaging with lie detectors or as evidence in court cases (Ienca, 2021). As the implications become more evident, ranging from bodily to social to legal, neuroethics has given rise to the concept of "neurorights" (Ienca, 2021). New developments and implications hold the potential to create and reconstitute certain human rights.

2.7 Opportunity for a Dashboard for Responsible Research in Neurotechnology

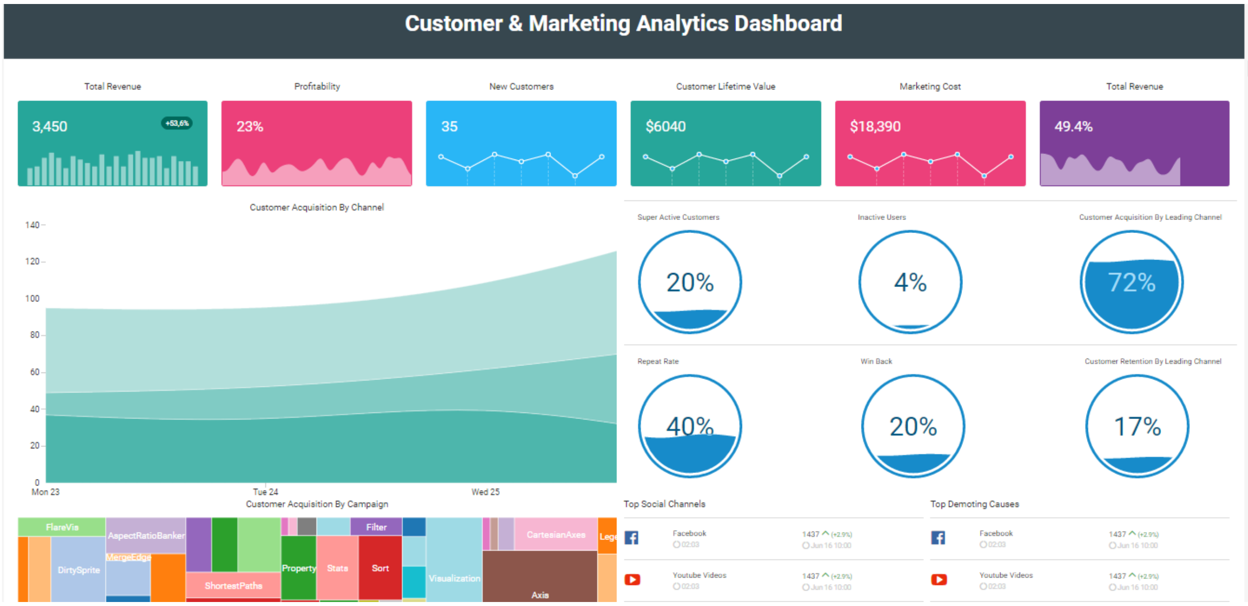
The IEEE Standards Association is one of the key organizations working towards creating substantive and inclusive standards for brain-computer interfaces. Dr. Ricardo Chavarriaga, a primary author of the Standardization of Neurotechnology for Brain-Machine Interfacing article published by the IEEE SA IC, spoke to how rapidly certain parts of the document became outdated after publishing (Yuste et al., 2021). Even within the relatively short time frame of a year, breakthroughs in the field rendered many components of the document irrelevant. This process can be seen across the entirety of the field, where standards and recommendations could be improved to keep up with the speed of development (Wexler &

Reiner, 2019). To confront this issue, many independent groups, such as the IEEE SA (IEEE, 2020), the OECD (OECD, 2019), and many other organizations, are working to create up-to-date guidance for developing neurotechnologies.

With this variety of organizations developing guiding documents, there comes a need for collaboration, and our centralized dashboard provides an outlet for sharing this critical information. By delivering one search location that compiles all known standards documents into one database, those researching for these documents will spend less time looking through numerous databases for the same information. Increasing a culture of sharing data and best practices will help the field innovate, too, according to conversations we had with professionals in neurorehabilitation at CHUV. Our dashboard has numerical representations of the types and quantities of resources in our database to help users see what is available and missing from the collection at a glance. This will increase trust that our database is unbiased and far-reaching throughout the field of neurotechnology, with the hope that standards organizations and other professional groups will like to add and contribute to the growing conglomeration of documents. Open access to all data in our database will allow for an independent review of the quality and quantity of sources on various topics. This data-driven approach will help improve the speed and quality of advancements in this field. An example of a data-driven dashboard is shown in Figure 2 below.

Figure 2. Example Web Dashboard

A data-driven web dashboard for marketing analytics.



Note. From *Marketing Dashboard*, by HelicalInsight & OpenSourceBI, 2015, Wikimedia Commons (https://commons.wikimedia.org/wiki/File:Marketing_dashboard.png) under CC BY-SA 4.0.

2.8 Case Studies

We examined two case studies to provide insight and learning opportunities on the two most significant components. The first case study looks at the ethical outcomes for those involved in invasive neurotechnology studies. The second case study describes the development of a web-based dashboard for use in intensive care units (ICUs).

2.8.1 Case One: Post-Trial Access to Brain Implants

Lázaro-Muñoz et al. (2022) constructed a study of twenty-three researchers and twenty-one participants to gauge their thoughts toward access to helpful brain implants after completing a study. The participants were patients in other studies who received brain implants to investigate treatments for their diagnosed neurological disorders. During the interviews, a majority believed that if a device increased the patient's quality of life, they should have the opportunity to keep the implant. Much concern was noted about who the responsible party should be for covering costs associated with extended access. The authors noted that four major stakeholders could be responsible for supporting continued use: device manufacturers, research teams, insurance companies, and participants. Arguments were made for and against all four groups, but the authors claimed that it is difficult to determine who should be accountable. They stated that insurance companies might not cover experimental medical devices, device manufacturers may discontinue a device after a trial is completed, participants underwent surgery for the betterment of science and feel they should not be held liable for costs, and research teams may not have the funding to continue covering the implants.

The study concluded with a discussion calling for better standards to enable more opportunities to manage the patients' implants post-trial ethically. Without a framework to decide how to protect patient access after the conclusion of a trial, patients helped by implanted devices were burdened with either removing the beneficial devices or paying high costs with high risks to keep them. These issues arose even with a proper consent process prior to the implantation of a device. Some patients involved in the often multi-year studies forgot about having the consent discussion altogether.

2.8.2 Case Two: Development of a Web-Based Dashboard for COVID-19 ICU Use

The COVID-19 pandemic brought the need for rapid response to hospitals around the globe. To aid nurses and other healthcare professionals in Brazil, de Morais Barroca Filho et al. (2021) worked to develop a web-based dashboard called Leitos to help manage ICU bed capacity and track COVID-19 cases in hospitals in Rio Grande do Norte, Brazil. Their team implemented Agile Software Development (ASD) as the guiding principle for the fast and adaptable development of Leitos. According to the study, ASD does not explicitly state any objectives to meet while developing software; rather, it suggests methods for team collaboration, communication, and the ability to iterate quickly to meet design requirements. Their team consisted of "a scrum master, responsible for impediments removal; a software architect, responsible for conducting and documenting the development process; and three developers, responsible for supporting the requirements elicitation and the implementation of the system" (p. 325). They held daily meetings to discuss deliverables, raise issues, and ensure developers were on task with the requirements. With an administrative structure in place, the Leitos team spent ample time creating a requirements document based on discussions with the State Health Department personnel who would be using the dashboard. This document ensured that the team clarified and met all stakeholders' demands. The team used a single-page design to present information the fastest way possible to avoid moving around the dashboard through various menus, as seen in Figure 2. Through role-based authentication, the team could implement security measures that provided access to different information only to those who needed it. Using a secure web-based communication protocol, Hypertext Transfer Protocol Secure (HTTPS), the team was able to lock down sensitive health information from anyone trying to gain unauthorized access to the dashboard. All of this was achieved using free and openly available software programs.

This case study guided our team's decisions in organizing a research team and a software development team when working on the main deliverable of this project, a web-based neurotechnology standards dashboard. Agile Software Development was a practice familiar to some of the team, so this study helped those unfamiliar to learn about the benefits and drawbacks of using such a framework. With only seven weeks to complete the deliverable, daily meetings and quick turnarounds on goals would be necessary, but this could lead to overworking team members. As technical considerations were made for the software side of the dashboard, the free software used by the Leitos team was researched and vetted for possible use in our application.

2.9 Summary

Neurotechnology is a vast subject that can be found at the crossroads of many diverse disciplines. Experts in electrical engineering, computer science, biology, and many other practices come together to develop technologies that have the potential to positively impact society and improve the lives of millions of people around the world. However, due to the potentially life-threatening experiments within the field, much of the research in neurotechnology needs to be carefully monitored and deemed ethical before proceeding with commercial applications. When technology is constantly being improved and created, standards are often outdated and must be revised as advancements are made. We created a web-based dashboard for responsible research in neurotechnology where researchers, developers, regulatory bodies, and ethicists of the matter can quickly find relevant information. This will create a place where the entire neurotechnology community can unite and continue to push the field's boundaries.

Chapter 3. Methodology

The goal of this project was to create an accessible web dashboard that would present information to professional stakeholders on the latest developments in neurotechnology standards to support responsible research. To achieve this goal, we:

1. sought to familiarize ourselves with the complex field of neurotechnology through intensive research of the problem space and interviews conducted with industry professionals
2. surveyed existing documents from various organizations and explored ways to categorize them for submission in our accessible database
3. developed a web-based dashboard that effectively searches a resource-rich database which allows future teams to build upon it in future adaptations of this project

This chapter describes the methodologies we employed to achieve our objectives and explains key details and processes necessary for our success.

3.1 Background Research

Before beginning project work in Switzerland, we researched the state of the art in neurotechnology devices, research, and standards. This research included documents related to neurotechnology research, dashboard development, and background on the work done by our potential interviewees. As a team, we increased our awareness of devices like Brain Computer Interfaces (BCIs), electroencephalograms (EEGs), and the need for standardization in developing these devices. This research familiarized us with the field and gave us sufficient knowledge to engage in intelligent conversations with our sponsor and interviewees.

We began our project in Switzerland by conducting a key informant interview with the project's primary sponsor, Dr. Ricardo Chavarriaga. This interview highlighted the project's area of focus and established the project scope and timeline to ensure we successfully created our deliverable. Following the key informant interview with our sponsor, we created three ideal interview profiles identifying broad characteristics and qualifiers of potential interviewees. The ideal candidates were experienced in research, industry, or regulation aspects. We supplied these profiles to our sponsor, Dr. Chavarriaga, who, utilizing his industry connections, suggested several professionals to contact. We emailed them, introducing ourselves and our project, and set up a time to interview. These interviews helped us gain perspective on the use case for our deliverable, allowing us to create a product that is beneficial to the users.

Before any interviews occurred, the participants were made aware of why they were being interviewed and consented to participate in the project. An informed consent statement disclosed that, if agreed to, the interviews would be recorded and kept in a secure Google Drive folder only accessible by our team, see Appendix A. They were also informed that the notes and information obtained during the interviews would not be shared with anyone outside the project. We also asked whether we could quote the interviewee directly or indirectly within our report. We utilized a set of questions as seen in Appendix B.

If the interview took place in person, we asked for permission to record the interview using voice memos. Virtual interviews were recorded through a virtual meeting platform's internal recording tool. The interviews were deleted from any personal devices and uploaded to our secure Google Drive. The recorded interviews were transcribed into text for easy access at later points.

3.2 Organization of Information

If professionals feel that there is any bias or incompleteness in the collection of documents available on NeuroDash in the future, they will lack trust in the collection and may not endorse its functionality. For this reason, identifying the correct resources to add to our website was an imperative aspect of our research. We understand that we did not have the time or experience to create an all-inclusive database containing only relevant documents, so we decided to limit our MVP database to around fifty of the most diverse documents as possible to simply showcase the functionality of all of our search filter features.

The documents we selected were identified through our own research, as well as with the help of industry professionals such as our sponsor and our interviewees. In the future, a more complete collection of documents will be added to the database. To ensure that users are aware that the dashboard is still a work in progress, we left a paragraph in our mission statement that reads as follows: “The neurotechnology standards dashboard is a project that aims to support responsible neurotechnology developments by providing a centralized location for relevant standards documents and guidelines. The goal of the website is to eliminate the need to constantly search various standards organizations for the most up-to-date standards. Not only would it speed up the time to acquire resources, but also improve the accuracy of this process. Being able to view similar resources across a variety of sources allows for confident comparisons and educated decisions.” Once NeuroDash leaves the MVP stage, this disclaimer will no longer be necessary.

The categorization of our documents will ultimately determine how easily users will be able to navigate through our search function and find what they need in an intuitive manner. Our search filter parameters included the title, the author(s), keywords, the Digital Object Identifier (DOI), the publication date, the organization that published the resource, the language that the document was written in, the access type (whether the document is publicly or privately accessible), and the industry to which the resource is applicable to. This combination of categories created an optimal user experience that gave users the freedom to sort through documents in a multitude of unique ways.

3.3 Constructing

We took steps to grow the web development skills necessary to create a product up to the quality of work displayed by our sponsor. Some team members have been working on web development skills for over eight years and were willing to teach the other members to grow their skills to decrease the workload overall. Many internet resources exist, spanning all aspects of web development (Codecademy, 2023), and they were used alongside one-on-one help from teammates. These resources exist as videos, books, and courses. We identified two books to learn Django, a Python web framework, and Node.js, a JavaScript web framework (Herron, 2020; Ravindran, 2018). With recommendations from team members knowledgeable in this field and combinations of internet resources, we successfully developed our skill set to deploy a web-based dashboard for our sponsor.

Most websites today consist of a database, backend, and frontend, which all work together to bring data to users in an accessible format. The backend of a website allows for communication between the database and the user interface, also known as the frontend, which presents the database content in human-readable form. After a discussion between team members, we settled on using a PostgreSQL database, the Django framework as the backend, and React, a JavaScript framework, as the frontend. All of these software are open source, a trait desired by our sponsor. These frameworks are also easy to learn for team members slightly familiar with Python. Most of the team has a background in Python but lacked experience in JavaScript which was the main factor in deciding on Django over Node.js. In addition, Django comes packed with features such as an admin interface, an API constructor, and a simple object relational mapper (ORM) for communicating with the database. The database holds all the standards documents we found with their categorizations. Documents can be added and removed from the database only by specifically assigned admin users. Many frontend frameworks are available today, but experience was a major factor in deciding to use React. Team members have had experience using both the Angular and React frontend frameworks. Angular has a steeper learning curve which would hinder our ability to develop a full product in seven weeks. Much of the frontend will be written in plain HTML which allowed group members with little to no JavaScript experience the opportunity to contribute to the frontend which will be seen by future users.

Our sponsor clarified that this dashboard is a large undertaking and that we needed to first work to create an MVP (R. Chavarriaga, personal communication, April 6, 2023). An MVP is “a product with enough features to attract early-adopter customers and validate a product idea early in the product development cycle” (ProductPlan, 2023, para. 1). We learned how to create initial drafts and iterations of the dashboard using the design tool, Figma (Figma, 2023). As the dashboard was developed, iterations were presented to and evaluated by our sponsor, our interviewees, and later, a focus group.

A focus group allows participants to interact and share thoughts with each other, whereas, in an interview, the participant can only interact with the interviewer (Berg & Lune, 2017). Our focus group consisted of members from the IEEE SA working group on Neurotechnologies for Brain-Machine Interfacing. Our sponsor, Ricardo Chavariaga, is a chair of this working group. Since these participants could be potential future users of the dashboard, the feedback they provided was extremely influential in the development of the dashboard. The participants included representatives from different disciplines related to our project, such as academia and clinicians, industry, and regulation. This was to ensure diverse opinions were formed about our website and encouraged conversations and sharing of ideas amongst the participants.

In the focus group, participants gathered virtually to explore our dashboard and provided feedback on specific aspects of the interface and usability. The participants received our informed consent statement prior to participating. Before the meeting, we prepared a presentation showcasing the current version of the dashboard and ideas for features. The participants asked questions and provided feedback in an open discussion facilitated by all four group members. Key ideas were noted, and we identified constructive feedback to learn what information belongs on the dashboard.

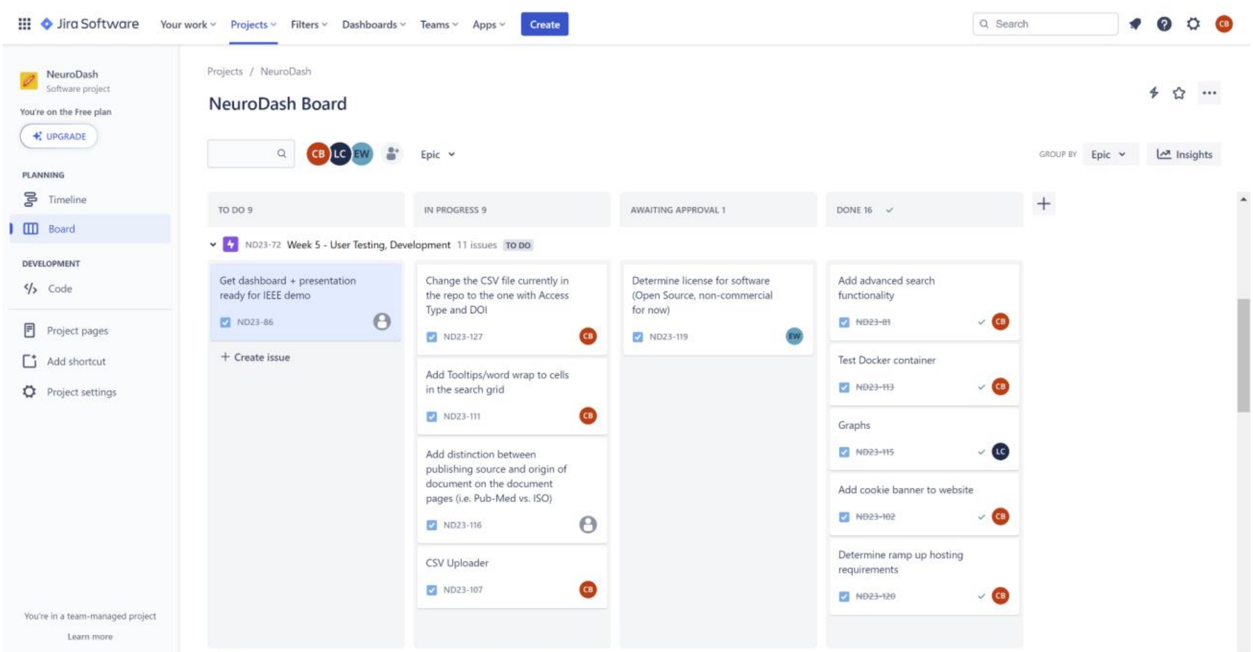
The most important quality of our final product was the updating of resources and features by approved users and future developers. In the scope of this project, approved users will be assigned by our sponsor, and ideally, as the project grows, this verification process will leave the hands of an individual and become a community-trust-based process to be outlined by future developers and stakeholders. The sponsor's vision for the dashboard is one that can be built upon through further projects and efforts after we finish our time at ZHAW. In order to make sure our dashboard MVP is able to act as a starting point for further development, maintaining clear and extensive technical documentation throughout the project is of utmost priority. Decisions made about the development have been well documented. Alternative options for all decisions have been explored and final decisions have been thoroughly justified.

3.4 Project Administration

In order to complete this intensive deliverable in a relatively short time frame, our team heavily prioritized staying organized and keeping all decisions and choices well documented. We utilized existing software development methodologies to run a fast-paced development team effectively. Agile development is one of the most prominent methodologies software development teams use today as it allows teams to provide deliverables to their stakeholders in small pieces rather than a final full launch (Atlassian, 2023). By making smaller components out of the larger product, we were able to ensure that every need was met to the best possible quality.

To organize the project, we created weekly milestones and goals to update and track throughout the week. The team explored multiple project management software but settled on a program called Jira, an industry-standard project management software. An example week from our tracking board can be seen in Figure 3. Using Jira provided the team with a new skill as well as allowed us to create, track, and delegate tasks to be led by individual group members. Tracking and organizing the smaller details of our project not only helped keep the team accountable and on track, but also encouraged us to document each technical process easily.

Figure 3. Jira Tracking Board



Note. The four columns denote categories for completion, starting with 'To Do' and ending with 'Done'.

Chapter 4. Results and Analysis

By following and adapting our methodology throughout the project, we achieved our outlined objectives and produced a working MVP to be used by our sponsors and stakeholders. The results from our three objectives are presented in this chapter, exploring our key findings and the outcomes of the decisions we made. We were successful in creating an easily searchable database of neurotechnology standards, guidelines, and other resources with input from various interviews, research, and personal communications.

4.1 Research and Familiarization

At the beginning of the project, our group sought to better understand the field of neurotechnology by observing and speaking with the people who work in it. We began this pursuit of understanding by conducting a key informant interview with our project sponsor in Switzerland, Prof. Dr. Ricardo Chavarriaga. In completing this interview, we gained insight into how to approach collecting research data that would help us with the construction of our dashboard. We set a seven-week timeline with goals and milestones for each week, identified potential interview candidates, and defined a clear project scope to ensure success in this fixed amount of time.

We made it a priority to interview people with diverse backgrounds so that we could hear voices that represent as many groups and organizations as possible. In addition to arranging interviews with professionals, we were able to visit a hospital and gain insight into problems that doctors face on a daily basis when rehabilitating patients with cognitive motor dysfunction (CMD). We were very lucky to be able to interview a few of these medical professionals as well, and with the information gained from all of these interviews, we were ready to create a dashboard that met everyone’s needs.

4.1.1 Defining Project Scope

During our key informant interview, our team, and Dr. Chavarriaga reviewed our timeline and emphasized that, due to our strict time frame, we were to develop an MVP with key functionality implemented to demonstrate to stakeholders. We found that a working product was more valuable to our sponsor than countless features and that our database should be a small but comprehensive view of existing standards and resources for neurotechnology research and development.

Through the utilization of the project tracking software Jira, we were able to break our numerous tasks into smaller pieces for delegation to team members. By breaking our tasks into week-by-week segments, we kept up with deadlines and were able to provide new features and important updates to our sponsor on a weekly basis. With categories such as To Do, In Progress, Blocked, and Done viewable by the whole team, we were able to keep each team member accountable for tasks needing completion by certain dates. We found this approach highly useful and would recommend that future teams implement similar task tracking.

Understanding the scope laid out in this initial meeting, we communicated with potential interviewees to set up interviews that would help us learn more about our stakeholders and how we could tailor our product toward their needs. Our interviewees had diverse backgrounds that brought more insight into the importance of our project and how they would utilize a tool similar to our proposed dashboard.

4.1.2 Interview Takeaways

As mentioned by Dr. Chavarriaga during our key informant interview, our interviews with neurotechnology professionals needed a purpose. Our team decided that the primary takeaways from these interviews would be determining if interviewees would use our dashboard or not, and if using our dashboard would be more convenient than their traditional methods of gathering documents. Furthermore, we wanted our interviewees to suggest possible search filter fields and ways to categorize documents, as well as any specific documents that they would like to see included in our database.

While constructing our questions for the interviewees, we found that the purpose of the interview may vary slightly depending on the field that the interviewee has expertise in, from medical clinicians to engineers building BCIs. We also realized that professionals from different backgrounds have different preferences and priorities when it comes to categories and documents that they would like to see on our dashboard. Moving forward, it was our job to try to accommodate the dashboard for all of these different stakeholder needs.

Our first interview was with Martijn de Neeling, a medical doctor and Ph.D. student at the Amsterdam Medical Centre. Martijn shared insight on gathering standards documents as a medical researcher, saying that sometimes the validity of a standard lies in how many times it's been cited, or whether or not it is approved by organizations such as the United States Food and Drug Administration (FDA), the National Institutes of Health (NIH), or the IEEE. Upon reviewing our dashboard, Martijn suggested adding a categorical search filter that divided results by the purpose of the document, giving examples such as data reporting, data sharing, and designing new applications.

We then interviewed Mark Melynkowycz, a lead product developer at IDUN Technologies, and he provided us with the viewpoint of an experienced member in the consumer development of neurotechnology. He mentioned that the primary difference between medical-oriented and consumer-oriented standards is the intensity of the standard. Medical-oriented standards require extensive efficacy and safety testing which sets them apart from the less rigorous consumer standards. Prompted by his feedback, we chose to add another category to the database that distinguishes standards between clinical, more medically focused standards and non-clinical, commercial development-focused standards. Dr. Melynkowycz also spoke about the benefit of having a centralized database augmented with AI technologies to improve usability and credibility. Unfortunately, AI integration in the form of natural language processing (NLP) and chatbot assistance lies outside the scope of the project. However, these features could be key parts of future developments of the project and will be explored in the conclusion and recommendations chapter.

One of the most important questions was asking our interviewees how they accessed documents and the types of documents they received from these resources. Getting recommendations directly from these experts is imperative to have relevant documents in our database. However, to ensure that there are no biases in our collection of documents, it is equally imperative to consider that any recommendations given by certain professionals may just be personal preferences of those individuals and may not reflect what is considered popular or relevant by the field as a whole.

4.1.3 Experiencing Real-World Motivation - Lausanne University Hospital

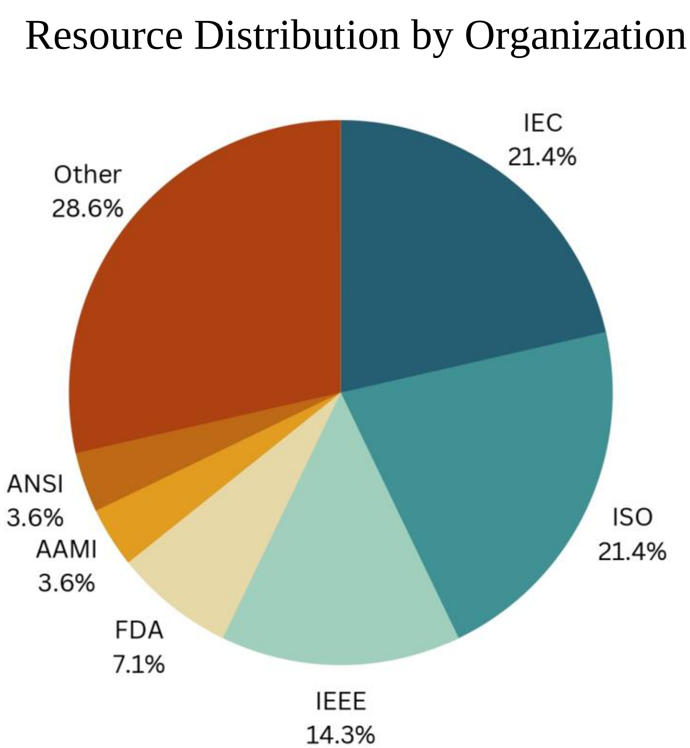
From our interviews, we understood that our project would help researchers and clinicians, industry developers, and standards board members efficiently locate standards documents. However, the importance of our project became unclear when we thought about its usefulness in situations involving actual patients. With help from the Lausanne University Hospital (CHUV) and their clinical neurological work with coma and other disorders of consciousness (DOC), we experienced one of the numerous real-world applications of neurotechnology. CHUV's neurological team hopes to gain a full definition of coma and find a definition that can better explain the nuanced condition between medical professionals. We learned that, due to the lack of a universal standard definition of a coma, doctors cannot properly diagnose patients presenting a variety of different symptoms. In the intensive care unit (ICU) at CHUV, we saw how patients who are expected to recover still show symptoms that could categorize them into a coma diagnosis. We learned that through the use of neurotechnologies like BCIs and AI-based technologies like facial recognition (Erikkos Maslias, personal communication), doctors will be able to better diagnose patients showing coma symptoms, but there are not enough rigorous standards available to reliably use these upcoming technologies.

Today, many hospitals have steps for diagnosing coma patients, but they tend to vary drastically across the globe. The coma diagnostic process at CHUV, for example, takes a different approach than most hospitals, spending 5 hours a day with their patients. Other hospitals may not do this due to cost or lack of evidence due to incomparable results (CHUV Presentation at the lunch table, personal communication). This experience underscored one of our MVP's goals: eliminate drastic variation in professional practices by presenting multiple reliable guidelines for comparison and decision-making. The applicability of the MVP extends beyond coma diagnosis, and it will allow clinicians and other professionals to formulate strong standard practices and diagnostic processes.

4.2 Collecting and Categorizing Standards Documents

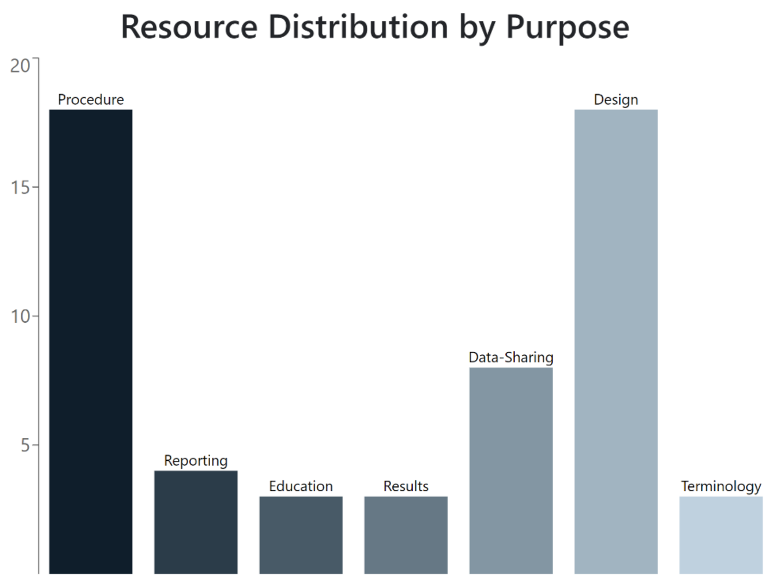
The collection of individual standards, guidelines, and other resources was a significant component of our deliverable. Given the limited scope of the project and the unrealistic possibility of including every single document that pertains to neurotechnology, we had to be intentional with what we would include and why to ensure a representative sample of documents was included in our database. We found that, at this stage, a small set of diverse documents was more valuable to potential users than a large, unfiltered set of every document available from numerous sources. We sought documents originating from a multitude of publishing organizations (see Figure 4), representing various levels of technical specificity, and covering a variety of purposes (see Figure 5). In the end, we collected fifty-four individual standards documents representative of the expected final collection. The collected sample of documents was held in our database to demonstrate the functionality of the search and filter functions and give potential users an experience similar to a database of complete findings.

Figure 4. Database Composition Pie Chart



Note. This pie chart showcases the organization distribution of the fifty-four documents currently stored in our database.

Figure 5. Database Composition Bar Chart



Note. This bar chart from the home page of the dashboard updates automatically to show users the make-up of resource purposes in the database.

After we added these documents, we had to categorize them in a way that would be valuable to the end user. Some categories such as publishing organizations or the document type were self-fulfilling and straightforward; however, others were more subjective. Creating these categories proved difficult as we are not neuroscientists and do not have the knowledge or experience to decide what categories were valuable to professional developers and researchers. We sought feedback and insights into how professionals interacted with standards in their everyday work.

Dr. Martijn de Neeling, a clinical researcher specializing in deep brain stimulation research, suggested implementing a stratification by purpose for standards in an interview with him. He said that when looking for standards, he often looks for one that applies to a specific purpose such as the design, data-sharing, or reporting aspect of neurotechnology development (personal communication, September 13, 2023). We adapted his suggestion of the purpose category to include “procedure” and “education” to encompass all the documents we included in ,the database.

We constantly updated the categories we used in the database as per the feedback we gathered from professionals as well as our sponsor. Some categories recommended by these professionals included whether the document is publicly available or requires purchasing, the areal use case, and the Digital Object Identifier (DOI) if the resource is a published article. In the final MVP, every standard in our database matched the format seen in Table 1. Unfortunately, some of the categorization fields have some degree of subjectivity.

Table 1. Document Categorization

Document Attributes	Attribute Details
Title	Document title, required
Year of Publishing	Date when the document was published, required
Publishing Organization	i.e. IEEE, ISO, IEC, ANSI, journals, etc., required
Author	Author names or working group name, required
Standard ID	Publishing organization's document ID, optional
Purpose	Education, Reporting, Data-Sharing, Design, Procedure, etc., required
Use-case	Clinical or Non-Clinical, required
Key Words	Words that are relevant to the information contained in the document, optional
Resource Link	Link to the document's original page, optional
Description	Abstract or description copied from the document page, required
Document Type	Standard, Guideline, Journal Article, etc., required
Language	English, French, etc., required
Access Type	Public or Private, required
DOI	The DOI of the resource, optional
Created	The date when the document was uploaded, automatic
Updated	The date when the document was edited by a user, automatic

Note. This table contains details of how the documents we collected were formatted for our database

4.3 Developing the Web-Based Dashboard

Developing and deploying a web-based dashboard was the key deliverable for this project and given the seven-week time constraint, it defined our project scope and presented the hardest challenge. In discussion with our sponsor, we found that this dashboard may be built upon by future student teams and possibly industry professionals. This vision for the success of this project guided our decisions and forced forward-thinking in every piece of the software development process.

4.3.1 Vision for Success

Our vision for success consisted of setting priorities for action items and key components to each piece of our full-stack application, consisting of a database, backend, and front end. A project this technically involved benefitted from prioritizing components to avoid escaping the scope we set, and it also guided the decisions made on each piece of our software stack. Considering our main three stakeholder groups, researchers and clinicians, industry developers, and standards board members, we limited our technical scope to three elements.

In order to be successful, we had to:

1. Create a database structure to hold categorized resources from varying organizations.
2. Develop a search feature to obtain desired resources from our database and display them to a user.
3. Have a working MVP prepared to showcase to a focus group, comprised of the IEEE SA working group on Neurotechnologies for Brain-Machine Interfacing two weeks prior to the end of our project.

We found a variety of approaches to achieving these elements, so setting low, medium, and high-priority elements aligned our ideas with our sponsor's idea for the outcome of this project. These priorities can be seen below in Table 2:

Table 2. NeuroDash Task Priorities

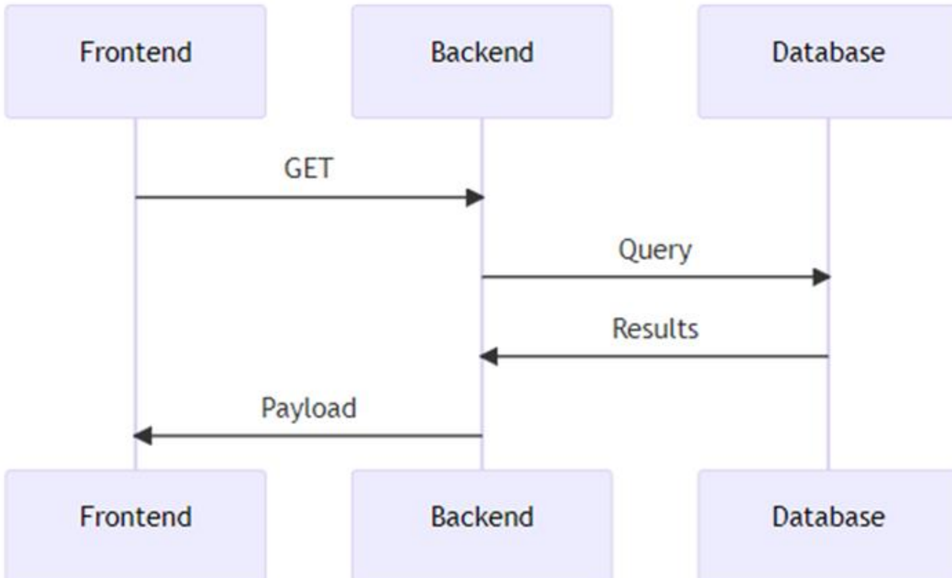
Priority Level	Tasks
High	Store and Categorize data in a database Search function, simple and more advanced filtering Administrator accounts Conduct interviews and implement feedback Add statistical representations to the front page Code version control
Medium	Data version control Styling the pages for visual appeal Ability to mass upload resources Data Analysis
Low	Separate user accounts

Note. Important tasks were subdivided into categories to determine their importance to team success.

4.3.2 Technical Challenges and Solutions

Our set of priorities greatly influenced the technical decisions we made while developing the product delivered to our sponsor. The main challenge with this project was the technical proficiency needed, specifically web development knowledge and programming experience, to create such an intensive full-stack website. Our team members had varying levels of experience in web development, but most had experience in the Python programming language, so we decided to use it as much as possible. This dictated how we would proceed in picking a database, backend, and frontend software. The second greatest challenge was keeping future development teams in mind when choosing our design and ensuring they have opportunities to advance our product and are not locked into the technologies we decided to use. Our database needed to be structured for searchability on known criteria and the backend and frontend had to be in a language both familiar to the team and powerful enough to quickly construct an application in under seven weeks. The three components of the dashboard and how they interact can be seen in the diagram in Figure 6 below.

Figure 6. Three Dashboard Components



Note. The framework for the dashboard and how the frontend, backend, and database interact with each other.

Utilizing the Python web framework Django to fit our backend needs allowed all team members to participate in development. It also has built-in technical features allowing for the rapid development of a database, endpoints for communication with the frontend, and our admin interface. To facilitate future teams to make their own decisions about what backend software to use, we constructed our backend in a way that allows it to easily transition to an entirely different software if desired. Future developers can create their own backend protocols in any desired language, and by accessing the endpoints we set up, they can still communicate with both the database and frontend.

We settled on using PostgreSQL as our database because of its compatibility with Django projects. Our familiarity with this database accelerated our success in developing a data model to hold our resources, achieving our first technical feature goal early into the project timeline. Another advantage of PostgreSQL is that it supports the ability to quickly develop a full-text search (PostgreSQL, n.d.), which was a high-priority technical feature of our dashboard. This text search was easy to implement in Django due to its great support for PostgreSQL. Future teams can expect high reliability, security, and customizability with this open-source database, which has had active development for over thirty-five years (PostgreSQL, n.d.).

The JavaScript framework React filled our need for frontend software. Individual team members did not have to learn the entirety of the JavaScript language to create pages, search bars, and other elements of our site due to React's abstraction from JavaScript. This made it easier for the entire team to contribute to the piece of this deliverable users will see. Our front-end code also does not rely on any specific database or backend to serve needed content to the user, so future teams can choose to move away from React completely and use all the other underlying components of the software stack with ease.

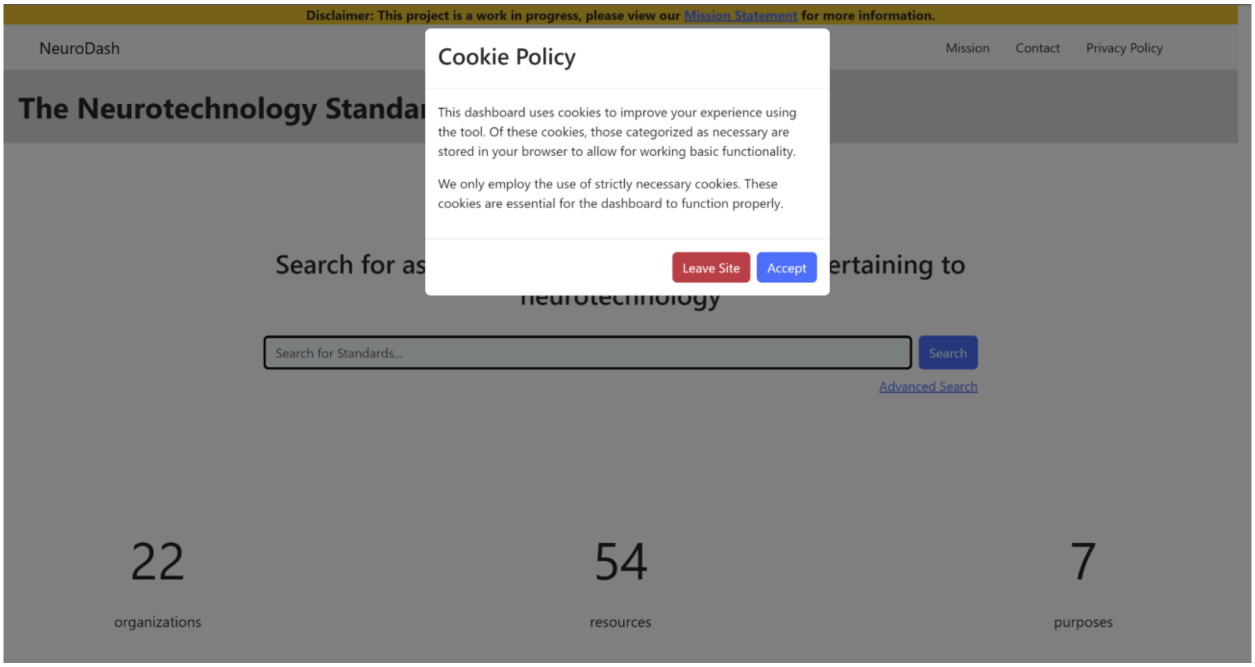
4.3.3 Using NeuroDash

The main technical decisions were settled to allow for ease of development, future construction on our MVP, and functionality. With the most challenging decisions made, the task of developing the dashboard took precedence. We were able to show weekly feature updates, and as this project progressed, our sponsor gained confidence in our abilities and his expectations for our work grew. Our ability to develop a product that met and exceeded the expectations of our sponsor strengthened our confidence in the decisions we made throughout the development of the dashboard.

The most important pages of our finished dashboard can be seen in the following images. All pages of the completed dashboard can be found in Appendix C. A comprehensive video demonstration of the dashboard's functionality can be found at https://youtu.be/lU2cym2oB5w.

When a user enters our website, they are presented with the option to accept our use of strictly necessary cookies or leave the site, see Figure 7. This is to ensure compliance with the ePrivacy Directive and the General Data Protection Regulation (GDPR) in the European Union (EU) (GDPR.eu, 2019), and it ensures compliance with the Swiss Federal Act on Data Protection (FADP) (New Federal Act on Data, n.d.).

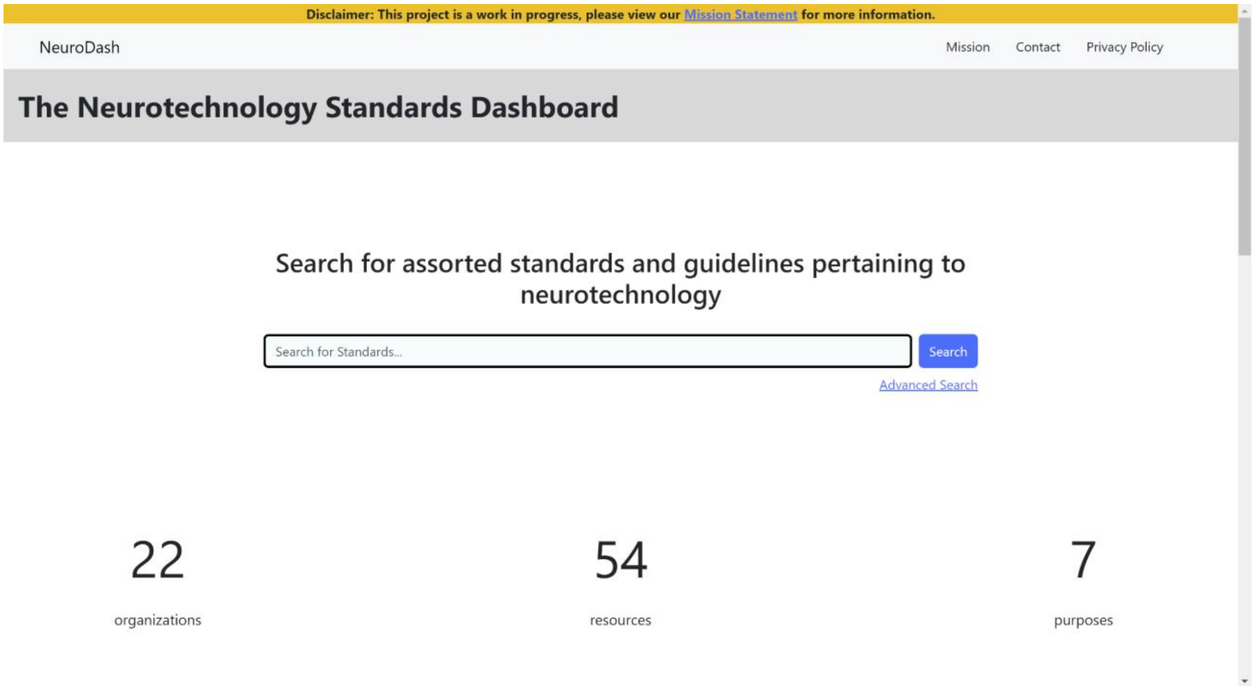
Figure 7. Cookie Policy Screen



Note. The cookie policy screen for compliance with the ePrivacy Directive, GDPR, and FADP. Users can accept our use of strictly necessary cookies or be directed away from the site.

After accepting the cookie policy, the home page presents the user with a search bar and statistics about the information in our database, see Figure 8. There is also a disclaimer banner at the top of the page indicating that this project is still a work in progress, pointing users to our Mission Statement for clarification (Figure C7).

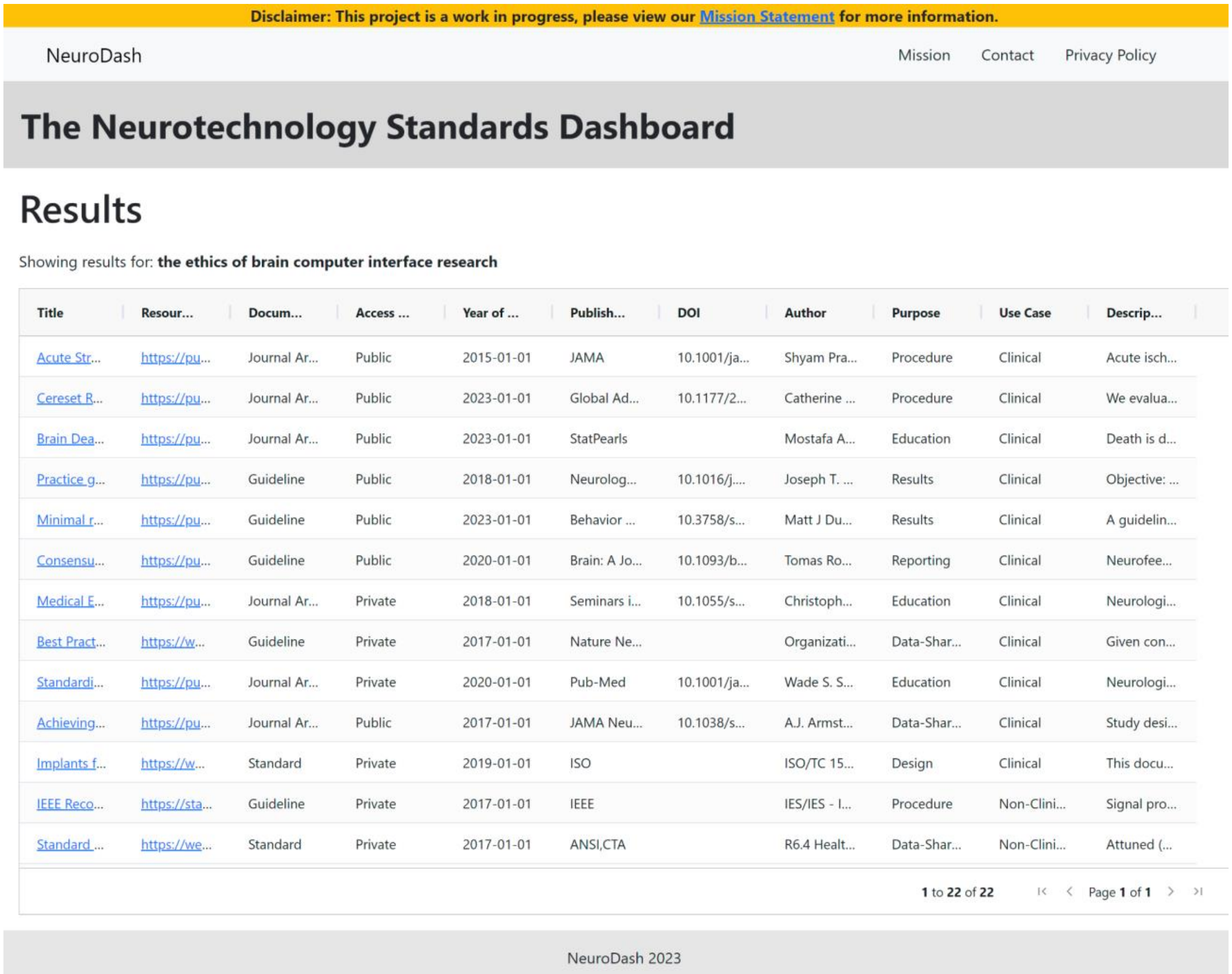
Figure 8. Dashboard Homepage



Note. The numbers on this page update automatically based on the status of the database. Scrolling farther down on this screen presents you with the graphs seen in Figure 4 and Figure 5.

Entering a search term, like ‘brain’, into the search bar will yield results containing the word ‘brain’. More complex searches like ‘the ethics of brain computer interface research’ will yield results containing the words ‘ethics’, ‘brain’, ‘computer’, ‘interface’, and ‘research’, as a result of removing the less-important stopwords ‘the’ and ‘of’. The results of this search can be seen in Figure 9 below.

Figure 9. Example Search from the Home Page



Disclaimer: This project is a work in progress, please view our Mission Statement for more information.

NeuroDash Mission Contact Privacy Policy

The Neurotechnology Standards Dashboard

Results

Showing results for: **the ethics of brain computer interface research**

Title	Resour...	Docum...	Access ...	Year of ...	Publish...	DOI	Author	Purpose	Use Case	Descrip...
Acute Str...	https://pu...	Journal Ar...	Public	2015-01-01	JAMA	10.1001/ja...	Shyam Pra...	Procedure	Clinical	Acute isch...
Cereset R...	https://pu...	Journal Ar...	Public	2023-01-01	Global Ad...	10.1177/2...	Catherine ...	Procedure	Clinical	We evalua...
Brain Dea...	https://pu...	Journal Ar...	Public	2023-01-01	StatPearls		Mostafa A...	Education	Clinical	Death is d...
Practice g...	https://pu...	Guideline	Public	2018-01-01	Neurolog...	10.1016/j....	Joseph T. ...	Results	Clinical	Objective: ...
Minimal r...	https://pu...	Guideline	Public	2023-01-01	Behavior ...	10.3758/s...	Matt J Du...	Results	Clinical	A guidelin...
Consensu...	https://pu...	Guideline	Public	2020-01-01	Brain: A Jo...	10.1093/b...	Tomas Ro...	Reporting	Clinical	Neurofee...
Medical E...	https://pu...	Journal Ar...	Private	2018-01-01	Seminars i...	10.1055/s...	Christoph...	Education	Clinical	Neurologi...
Best Pract...	https://w...	Guideline	Private	2017-01-01	Nature Ne...		Organizati...	Data-Shar...	Clinical	Given con...
Standardi...	https://pu...	Journal Ar...	Private	2020-01-01	Pub-Med	10.1001/ja...	Wade S. S...	Education	Clinical	Neurologi...
Achieving...	https://pu...	Journal Ar...	Public	2017-01-01	JAMA Neu...	10.1038/s...	A.J. Armst...	Data-Shar...	Clinical	Study desi...
Implants f...	https://w...	Standard	Private	2019-01-01	ISO		ISO/TC 15...	Design	Clinical	This docu...
IEEE Reco...	https://sta...	Guideline	Private	2017-01-01	IEEE		IES/IES - I...	Procedure	Non-Clini...	Signal pro...
Standard ...	https://we...	Standard	Private	2017-01-01	ANSI,CTA		R6.4 Healt...	Data-Shar...	Non-Clini...	Attuned (...

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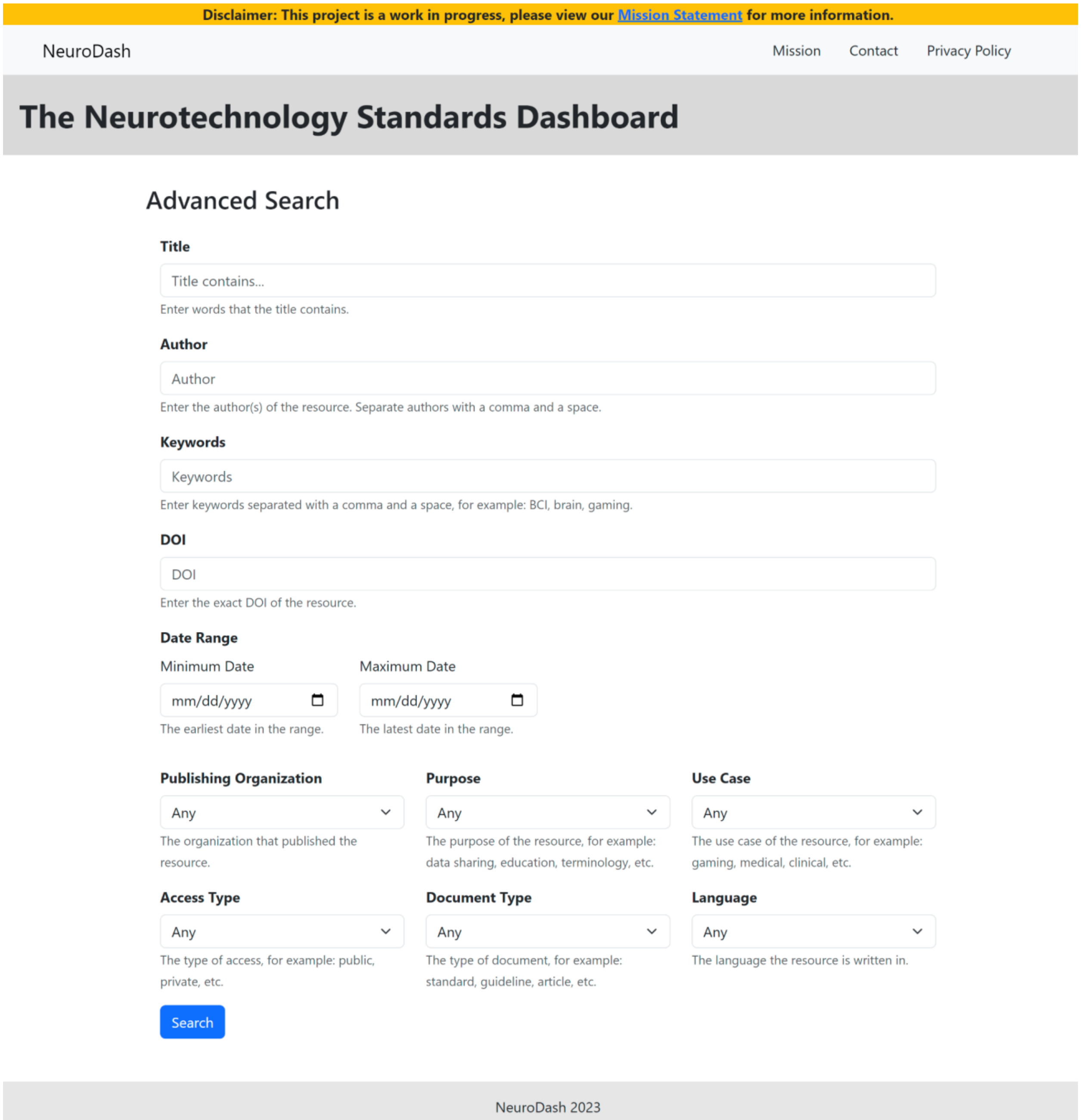
Note. This image shows an example view of what is returned from a complex search on the home page.

If the search bar on the home page is not tailored enough for a user's needs, we implemented an advanced search form that allows for searches based on categories and specific text fields present in Table 1, see Figure 10.

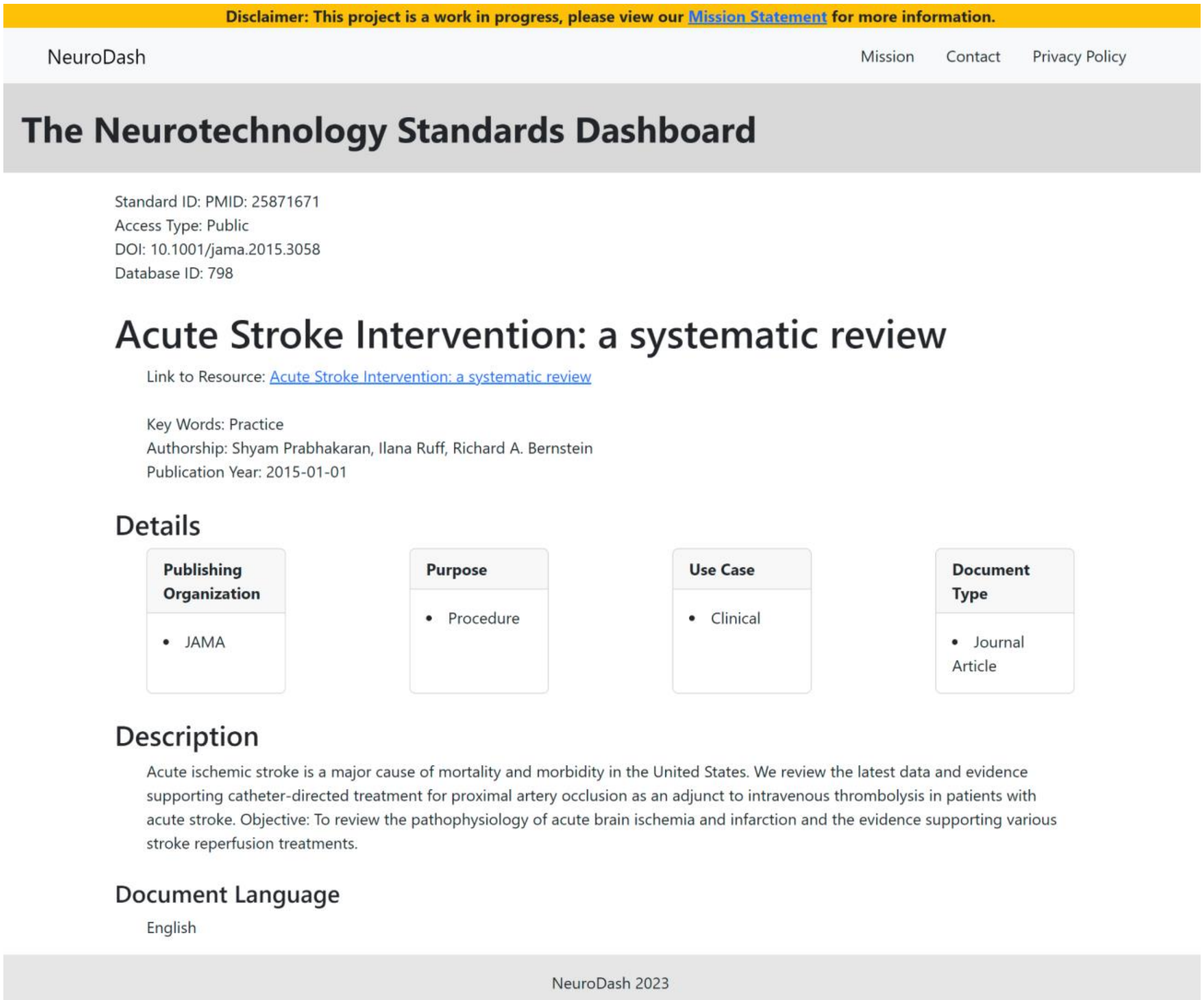
Figure 10. Advanced Search Form



Note. *Form validation has been applied to ensure that the Date Range cannot surpass the current date and that the minimum date is always less than the maximum date, and vice versa. The six dropdown fields at the bottom of the form allow users to select preset classifiers from the possible categories.*

The advanced search page returns a results page identical to the one returned by the home page search but with much narrower search parameters based on the items selected in the advanced search form. With a set of results returned, a user can filter and adjust the columns returned to make the table appear in their desired orientation; see Figures C13 and C14 in Appendix C. Once the user finds a resource they would like to know more about, they can click on the title of the resource in the left-most column of the Results page to bring up that resource's overview page, see Figure 11.

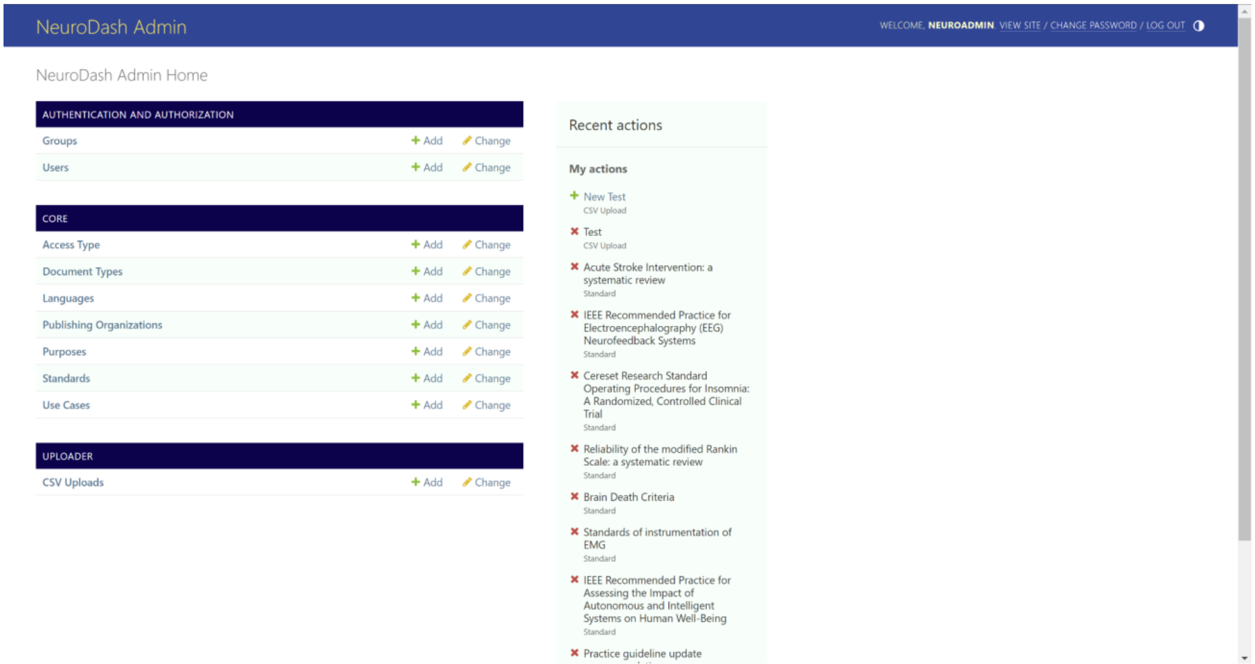
Figure 11. Resource Overview Page



Note. This overview page only provides publicly available information about the resource. All resources have a link to the location where it was found and a DOI number if applicable. The dashboard claims no ownership over the standards or other resources.

To upload new standards to the database, we have implemented the use of administrator accounts, which can access the uploading interface seen in Figure 12.

Figure 12. Administrator Interface



Note. Under the 'Core' heading, administrators can add access types, document types, publishing organizations, and individual standards. Under the 'Uploader' heading, administrators can bulk upload standards through our spreadsheet uploading tool.

The simple search implementation and ease of access to the overview pages allow users to quickly condense our database of numerous resources into a smaller set of sources relevant to their needs.

The successful implementation of the MVP spurred interest from professionals in our three stakeholder groups, showing promise for the future adoption of this dashboard as a staple in neurotechnology research as well as numerous other fields. Throughout the development of the dashboard, the team made significant efforts to create documentation on all of our decisions and technical processes to benefit teams working on this dashboard in the future.

4.3.4 Industry Feedback

Following these priorities and our confident decisions resulted in a working MVP which was able to be showcased to the IEEE Standards Association Industry Connections:

Neurotechnologies For Brain-Machine Interfacing group two weeks prior to our final project deadline (Neurotechnologies for Brain-Machine Interfacing, n.d.). Feedback from the IEEE SA IC included:

1. An IEEE SA contact point will be speaking about our efforts to the Standards Association which oversees the working group
2. Suggested the need for other Standard Development Organizations to be made aware of the project to gain support for its efforts
3. Focused on the need for results to be trustworthy and fully representative of any standards currently available

This feedback was crucial to defining our recommendations for future work in the areas of furthering development efforts, the curation of documents, and garnering support for our dashboard. The live demonstration and great reception by the IEEE SA IC group members encouraged our team and sponsor for the future life of this project. The weighty points about resource trustworthiness and standards representation showcased that there is much more to the viability of this project than our technical MVP. This spurred more conversation and ideas on how to enhance the quality of resources in our database to further its credibility.

4.3.5 Changing the Landscape of Neurotechnology Research

Through a series of interviews, personal conversations, research, and our tour of CHUV, we have seen how this project will bring about more collaboration in the field of neurotechnology research and development. Our project will facilitate more rapid developments in the field, and serve as the first centralized collection of up-to-date neurotechnology standards and guidelines. The MVP that we constructed is only the starting point of the project. The awareness we have built around the website and the need for a standards dashboard will hopefully garner greater support for the project from various organizations and actors.

Chapter 5. Conclusion

The goal of our project was to create a MVP for a web-based dashboard that would allow users to search for the most up-to-date standards and documents in the field of Neurotechnology. To accomplish this, we set three objectives that were achieved throughout the course of our seven weeks in Switzerland:

1. familiarize ourselves with the complex field of neurotechnology through intensive research of the problem space and interviews conducted with industry professionals
2. survey existing documents from various organizations and explore ways to categorize them for submission in our accessible database
3. develop a web-based dashboard that effectively searches a resource-rich database which allows future teams to build upon it in future adaptations of this project

Our dashboard provides an incredible opportunity for future work including furthering the user experience, improving how documents are curated, and ways to gain support from industry leaders. This chapter outlines the outcome of our collaborative efforts at the Zurich University of Applied Sciences in addition to a collection of recommendations on how to begin future work on this project. We end by discussing the implications of our work and how the continuation of this project can enhance our stakeholders' experiences, the field of neurotechnology as a whole, and end users of these technologies.

5.1 Deliverable

The MVP, the primary result of our work, was to create a readily accessible website for standards in neurotechnology. The website was expected to be complete and functional for demonstration to a professional audience. Originally, numerous features and a complete collection of resources were needed to perfect our MVP, but the project scope helped us recognize limitations and prioritize the critical over non-critical features. The critical functions were our ability to search the database, results pages, and resource viewing. Covering the essentials allows for the preparation for future work from other working groups by determining further developments and how to approach them.

5. 2 Recommendations

Throughout the development of our deliverable, we identified components which are vital for the future success of this project but lie outside of our project's scope. The MVP we built for NeuroDash is strong from a technical standpoint, but requires three key components to become widely accepted as a respected source for standardization in the field:

1. **Development**
   a. designing and improving features and tools within the dashboard tailored toward professional workflows
2. **Curation**
   a. efforts towards ensuring efficacy, trust, and accuracy of the resources in the database in order to be used by professionals
3. **Support**
   a. building collaboration across multiple organizations through growing publicity and awareness of the project

By implementing the strategies defined in the following sections for these key areas, NeuroDash will become the influential, collaborative, and trusted research tool Dr. Chavarriaga and ourselves envision it to be.

5.2.1 Development

In the spirit of collaboration, we recommend taking an open-source approach to furthering the technical development of the dashboard. Open source development allows for users and developers to collaboratively design and implement features. This approach takes the project away from the idea of this tool being owned by a single entity or organization and more towards a constantly evolving tool built by the same users who are utilizing it. Open source mitigates bias, improves collaboration and promotes idea sharing. Given the project's proximity to the IEEE Standards Association, we recommend taking advantage of the development tools available from the IEEE SA Open platform. The platform provides an adaptable development environment with infrastructure sufficient to meet the needs of our dashboard (*Welcome - IEEE SA OPEN*, n.d.). Utilizing this platform could greatly elevate the quality and accessibility of the dashboard.

Our MVP serves as just the baseline for the functionality of the dashboard, demanding further technical expansions. In terms of technical aspects of the dashboard, there are multiple key features we recommend implementing and expanding:

- Improving search algorithms with AI Integration — improve the accuracy and accessibility of results accessed through implementing natural language processing.
- User accounts — allow for users to save and more personally interact with standards and resources

These features are a few of many that have the potential to greatly improve the dashboard, turning it into a tool that satisfies the needs of the users.

5.2.2 Curation

As an MVP, NeuroDash has the key technical features implemented allowing it to be demonstrated to stakeholders. However, the information contained within our test data is not of the quality, diversity, or quantity needed to be trusted and used by professionals. Through our discussions with professionals in our stakeholder groups, we found that users of such a tool, especially medical practitioners, need to have complete confidence in the resources they consult. They have to be assured that they can trust that all of the resources returned from our dashboard contain all possible results for the terms, categories, and other qualifiers they searched for.

We collected over fifty resources through a manual process to prove the viability of our search functionality and other views within the dashboard. Professionals critiqued some of these resources during our interview process, and these critiques highlighted the subjectivity of labeling the nuance included in many standardization, procedural, and other documents. During this process, we noted improvements that should be made to the collection process for documents to be included in the database.

We were at the disadvantage of not having experience in the broad field of neurotechnology and were unequipped to label documents to the extent that our stakeholders expected. We recommend implementing systems that involve those who are most knowledgeable in the field to be the ones making these important decisions. These individuals should come from numerous stakeholder groups, especially a mix of industry and academic professionals. From our experience with the IEEE Standards Association Industry Connections: Neurotechnologies For Brain-Machine Interfacing group, we believe that individuals from existing or future working groups could focus efforts toward classifying documents. The downside of including human curators is the introduction of bias. Bias can stem from individuals' preference for sources from one organization, author, or journal. Individuals' biases would undermine the credibility of the database content.

We also recommend the inclusion of community feedback on documents to help limit the impact of document bias by allowing users to note the utility of a document through a vote, comment, or other metric. Allowing users to voice opinions on documents can also lead to more trust as users will feel part of the decision process. We recommend a process of verifying users' academic or professional credentials prior to allowing them to place feedback on documents to ensure feedback is not coming from individuals with no stake in the field.

The individuals, working groups, or organizations assigned to the task of labeling existing documents for addition to our database should be granted account access to upload documents to the database for immediate access by the community. With these changes to the resource curation process, we foresee quicker adoption of the dashboard into the usual workflow of our stakeholders.

5.2.3 Support

Interorganizational support of the dashboard is critical to its long-term success. The presentation the team gave to the IEEE SA Industry Connections (IC) group was the first step in a long process of building awareness of the project. While Dr. Chavarriaga and the Industry Connections group were familiar with the concept of the centralized standards database, seeing our implementation of the idea enforced that it can be a potential tool applicable to their line of work. A few professionals in attendance at the event wanted to build awareness of the dashboard within their organizations.

We recommend that further expansions seek support from primary actors from standards developing organizations. In the short term, further connections could be established with participants of the IEEE SA IC group who voiced their support for the project. From these connections, awareness of the project could spread to their superiors and be the first step of many to increase support for the dashboard. It is extremely important to gather support from more than one organization. In reference to the collaborative nature of the project, we recommend not affiliating the project efforts with a single organization; it should instead be a product of the collaboration of multiple organizations. However, this level of multi-organizational support may only be built over time, started by an initial, single organization effort. Support from organizations and individuals is the most influential factor for the project's success. Without the neurotechnology community's support, this project will not be further developed or adopted.

5.3 Closing Thoughts: The Significance of NeuroDash

Standards play a key role in efficiently sharing data between organizations, enabling collaboration, and enforcing the safety and ethicality of developments made in the field. Standards in neurotechnology are created rapidly by numerous SDOs, and this speed of development spread across many access points makes it difficult for our stakeholders to access the most up-to-date information. As this project continues to grow and gain support, we envision neurotechnology standards becoming more unified with the support of numerous credible SDOs. As collaboration increases, not only will researchers and developers benefit from the access of standards through our tool, but the products created by these researchers and developers will also increase in quality and accessibility, which will directly benefit their end-users. The project works towards ensuring the health and well-being of all people through medical technologies, practices, and their accessibility. The project also works to promote responsible innovations in scientific fields. These goals align closely with the United Nations Sustainable Development Goals three and nine (United Nations, 2023).

Our implementation of a standards dashboard provides a robust technical baseline to address the need for standards to be centralized and easily updatable. Standards play a crucial role in promoting developments made in the field, but without accessibility, they are underutilized. The web-based standards dashboard is a unique approach to this problem and feedback from professionals suggests that it is an effective solution. The dashboard framework has the potential to be taken beyond the field of neurotechnology, and implementing our solution across other scientific fields could solve the common issues associated with the utilization of standards. The development of NeuroDash amplifies the benefits of standards, encouraging and upholding innovation in the neurotechnology community. Responsible innovations in the field directly benefit clinical practices, medical research, device development and the in-field use of the technology. The effects of responsible innovations directly impact the quality of life of the commercial and medical end users of technologies created by researchers, clinicians, and industry developers.

References

ANSI/AAMI EC12:2000 (R2015)—Disposable ECG electrodes. (2015). American National Standards Institute. https://webstore.ansi.org/standards/aami/ansiaamiec122000r2015

Atlassian. (2023). *What is agile?* Atlassian. https://www.atlassian.com/agile

Baron, J., & Kanevskaia, O. (2023). Wearing multiple hats—The role of working group chairs' affiliation in standards development. *Research Policy*, *52*(9), 104822. https://doi.org/10.1016/j.respol.2023.104822

Berg, B. L., & Lune, H. (2017). *Qualitative research methods for the social sciences* (9th ed.). Pearson.

Caldwell, D. J., Ojemann, J. G., & Rao, R. P. N. (2019). Direct electrical stimulation in electrocorticographic brain–computer interfaces: Enabling technologies for input to cortex. *Frontiers in Neuroscience*, *13*. https://www.frontiersin.org/articles/10.3389/fnins.2019.00804

Codecademy. (2023). *Codecademy*. Codecademy. https://www.codecademy.com/

Cometa, A., Falasconi, A., Biasizzo, M., Carpaneto, J., Horn, A., Mazzoni, A., & Micera, S. (2022). Clinical neuroscience and neurotechnology: An amazing symbiosis. *iScience, 25*(10), 105124. https://doi.org/10.1016/j.isci.2022.105124

Cookies, the GDPR, and the ePrivacy Directive. (2019, May 9). GDPR.Eu. https://gdpr.eu/cookies/

de Morais Barroca Filho, I., Sampaio, S. C., Cruz, A. P., Ramalho, V. H. F., de Azevedo, J. A. R., & da Silveira, Á. C. (2021). More Agile than ever: The case study of the development of a dashboard for the management of ICU beds during the coronavirus outbreak. *2021*

IEEE 34th International Symposium on Computer-Based Medical Systems (CBMS), 324–329. https://doi.org/10.1109/CBMS52027.2021.00028

Elmalaki, S., Demirel, B. U., Taherisadr, M., Stern-Nezer, S., Lin, J. J., & Faruque, M. A. A. (2021). Towards Internet-of-Things for wearable neurotechnology. *2021 22nd International Symposium on Quality Electronic Design (ISQED)*, 559–565. https://doi.org/10.1109/ISQED51717.2021.9424364

Farah, M. J. (2005). Neuroethics: The practical and the philosophical. *Trends in Cognitive Sciences*, *9*(1), 34–40. https://doi.org/10.1016/j.tics.2004.12.001

Fiani, B., Reardon, T., Ayres, B., Cline, D., Sitto, S. R., Fiani, B., Reardon, T. K., Ayres, B. R., Cline, D. D., & Sitto, S. R. (2021). An examination of prospective uses and future directions of Neuralink: The brain-machine interface. *Cureus*, *13*(3). https://doi.org/10.7759/cureus.14192

Figma. (n.d.). *Home* [YouTube Channel]. Retrieved April 23, 2023, from https://www.youtube.com/channel/UCQsVmhSa4X-G3lHlUtejzLA

Figma. (2023). *Figma: The collaborative interface design tool.* Figma: The collaborative interface design tool. https://www.figma.com/

Groiss, S. J., Wojtecki, L., Südmeyer, M., & Schnitzler, A. (2009). Deep brain stimulation in Parkinson’s disease. *Therapeutic Advances in Neurological Disorders*, *2*(6), 20–28. https://doi.org/10.1177/1756285609339382

HelicalInsight OpenSourceBI. (2015). *English: Marketing dashboard*. Own work. https://commons.wikimedia.org/wiki/File:Marketing_dashboard.png#filelinks under CC BY-SA 4.0.

Herron, D. (2020). *Node. js web development: Server-side web development made easy with Node 14 using practical examples*. Packt Publishing, Limited. http://ebookcentral.proquest.com/lib/wpi/detail.action?docID=6276150

Ienca, M. (2021). On neurorights. *Frontiers in Human Neuroscience*, *15*. Scopus. https://doi.org/10.3389/fnhum.2021.701258

Ienca, M., Jotterand, F., & Elger, B. S. (2018). From healthcare to warfare and reverse: How should we regulate dual-use neurotechnology? *Neuron*, *97*(2), 269–274. https://doi.org/10.1016/j.neuron.2017.12.017

Kallio, H., Pietilä, A.-M., Johnson, M., & Kangasniemi, M. (2016). Systematic methodological review: Developing a framework for a qualitative semi-structured interview guide. *Journal of Advanced Nursing*, *72*(12), 2954–2965. https://doi.org/10.1111/jan.13031

Keebler, J., Taylor, G., Phillips, E., Ososky, S., & Sciarini, L. (2012). Neuroethics: Considerations for a future embedded with neurotechnology. In Fafrowicz, M., Marek, T., Karwowski, W., Schmorrow, D. (Eds.), *Neuroadaptive Systems: Theory and Applications* (pp. 333-350). https://doi.org/10.1201/b13019-16

Lázaro-Muñoz, G., Pham, M. T., Muñoz, K. A., Kostick-Quenet, K., Sanchez, C. E., Torgerson, L., Robinson, J., Pereira, S., Outram, S., Koenig, B. A., Starr, P. A., Gunduz, A., Foote, K. D., Okun, M. S., Goodman, W., McGuire, A. L., & Zuk, P. (2022). Post-trial access in implanted neural device research: Device maintenance, abandonment, and cost. *Brain Stimulation*, *15*(5), 1029–1036. https://doi.org/10.1016/j.brs.2022.07.051

Lewis, A., Young, M. J., Rohaut, B., Jox, R. J., Claassen, J., Creutzfeldt, C. J., Illes, J., Kirschen, M., Trevick, S., Fins, J. J., & and The Curing Coma Campaign and its Contributing

Members. (2023). Ethics along the continuum of research involving persons with disorders of consciousness. *Neurocritical Care*. https://doi.org/10.1007/s12028-023-01708-2

Neurosity. (2023). *Introducing the Crown*. Introducing the Crown. https://neurosity.co/

Neurotechnologies for Brain-Machine Interfacing. (n.d.). *Neurotechnologies for Brain-Machine Interfacing.* IEEE Standards Association. Retrieved October 4, 2023, from https://standards.ieee.org/industry-connections/neurotechnologies-for-brain-machine-interfacing/

New Federal Act on Data Protection (nFADP). (n.d.). The SME Portal of the State Secretariat for Economic Affairs. Retrieved October 9, 2023, from https://www.kmu.admin.ch/kmu/en/home/fakten-und-trends/digitalisierung/datenschutz/neues-datenschutzgesetz-revdsg.html

OECD. (2019). *OECD recommendation on responsible innovation in neurotechnology*. https://www.oecd.org/science/recommendation-on-responsible-innovation-in-neurotechnology.html

PostgreSQL: About. (n.d.). PostgreSQL. Retrieved October 9, 2023, from https://www.postgresql.org/about/

Precedence Research. (2022, December 22). *Neurotechnology market size to worth around USD 38.17 BN by 2032*. GlobeNewswire News Room. https://www.globenewswire.com/news-release/2022/12/22/2578707/0/en/Neurotechnology-Market-Size-to-Worth-Around-USD-38-17-BN-by-2032.html

ProductPlan. (2023). *Minimum viable product (MVP)*. ProductPlan. https://www.productplan.com/glossary/minimum-viable-product/

Ravindran, A. (2018). *Django design patterns and best practices: Industry-standard web development techniques and solutions using Python, 2nd edition*. Packt Publishing, Limited. http://ebookcentral.proquest.com/lib/wpi/detail.action?docID=5405693

Rodriguez-Oroz, M. C., Obeso, J. A., Lang, A. E., Houeto, J.-L., Pollak, P., Rehncrona, S., Kulisevsky, J., Albanese, A., Volkmann, J., Hariz, M. I., Quinn, N. P., Speelman, J. D., Guridi, J., Zamarbide, I., Gironell, A., Molet, J., Pascual-Sedano, B., Pidoux, B., Bonnet, A. M., … Van Blercom, N. (2005). Bilateral deep brain stimulation in Parkinson's disease: A multicentre study with 4 years follow-up. *Brain*, *128*(10), 2240–2249. https://doi.org/10.1093/brain/awh571

Roskies, A. (2021). Neuroethics. In E. N. Zalta (Ed.), *The Stanford Encyclopedia of Philosophy* (Spring 2021). Metaphysics Research Lab, Stanford University. https://plato.stanford.edu/archives/spr2021/entries/neuroethics/

Rooy33. (n.d). *Brain, Computer Chips, Technology*. Pixabay. Retrieved April 29, 2023, from https://pixabay.com/illustrations/brain-computer-chips-technology-5564173/ under CC BY-SA 4.0.

Schnakers, C., Vanhaudenhuyse, A., Giacino, J., Ventura, M., Boly, M., Majerus, S., Moonen, G., & Laureys, S. (2009). Diagnostic accuracy of the vegetative and minimally conscious state: Clinical consensus versus standardized neurobehavioral assessment. BMC Neurology, 9, 35. https://doi.org/10.1186/1471-2377-9-35

Shih, J. J., Krusienski, D. J., & Wolpaw, J. R. (2012). Brain-computer interfaces in medicine. *Mayo Clinic Proceedings*, *87*(3), 268–279. https://doi.org/10.1016/j.mayocp.2011.12.008

IEEE Standards Association. (2021). *Beyond Standards.* IEEE Standards Association. Retrieved October 9, 2023, from https://standards.ieee.org/beyond-standards/what-are-standards-why-are-they-important/

Sui, Y., Yu, H., Zhang, C., Chen, Y., Jiang, C., & Li, L. (2022). Deep brain–machine interfaces: Sensing and modulating the human deep brain. *National Science Review*, *9*(10), nwac212. https://doi.org/10.1093/nsr/nwac212

The Institute of Electrical and Electronics Engineers. (2020). IEEE Industry Connections (IEEE-IC) standards roadmap: Neurotechnologies for brain-machine interfacing. *IEEE Industry Connections (IEEE-IC) Standards Roadmap: Neurotechnologies for Brain-Machine Interfacing*, 1–100.

United Nations. (2023). *The 17 goals*. https://sdgs.un.org/goals

von Krogh, G., & Spaeth, S. (2007). The open source software phenomenon: Characteristics that promote research. The Journal of Strategic Information Systems, 16(3), 236–253. https://doi.org/10.1016/j.jsis.2007.06.001

Warwick, K. (2018). Neuroengineering and neuroprosthetics. *Brain and Neuroscience Advances*, *2*(1–5), 2398212818817499. https://doi.org/10.1177/2398212818817499

IEEE SA OPEN. (n.d.). *Welcome—IEEE SA OPEN*. IEEE SA OPEN. Retrieved October 9, 2023, from https://saopen.ieee.org/

Wexler, A., & Reiner, P. B. (2019). Oversight of direct-to-consumer neurotechnologies. *Science*, *363*(6424), 234–235. https://doi.org/10.1126/science.aav0223

Willett, F. R., Avansino, D. T., Hochberg, L. R., Henderson, J. M., & Shenoy, K. V. (2021). High-performance brain-to-text communication via handwriting. *Nature*, *593*(7858), Article 7858. https://doi.org/10.1038/s41586-021-03506-2

Worcester Polytechnic Institute. (n.d) *Marketing Communications Resources & Tools.* Worcester Polytechnic Institute. Retrieved April 29, 2023, from https://www.wpi.edu/offices/marketing-communications/resources

Yuste, R., Genser, J., & Herrmann, S. (2021). It's time for neuro-rights: New human rights for the age of neurotechnology. *Horizons: Journal of International Relations and Sustainable Development*, *18*, 154–165. https://www.jstor.org/stable/48614119

ZHAW School of Engineering. (n.d.). *Centre for Artificial Intelligence*. ZHAW School of Engineering. Retrieved April 21, 2023, from https://www.zhaw.ch/en/engineering/institutes-centres/cai/

ZHAW School of Engineering. (n.d.). *Media*. ZHAW School of Engineering. Retrieved April 29, 2023, from https://www.zhaw.ch/en/engineering/about-us/media/

ZHAW Zurich University of Applied Sciences. (n.d.-a). *Dr. Ricardo Chavarriaga*. ZHAW Zurich University of Applied Sciences. Retrieved April 3, 2023, from https://www.zhaw.ch/en/about-us/person/char/

ZHAW Zurich University of Applied Sciences. (n.d.-b). *Prof. Dr. Thilo Stadelmann*. ZHAW Zurich University of Applied Sciences. Retrieved April 3, 2023, from https://www.zhaw.ch/en/about-us/person/stdm/

Appendices

Appendix A. Informed Consent Script for Interviews

<u>Developing a Web-Based Neurotechnology Standards Dashboard</u>

Verbal Interview: Informed Consent Script

As a group of students from Worcester Polytechnic Institute (WPI) in Massachusetts, United States, we would like to invite you to participate in an interview for our research to learn more about neurotechnology and its implications. The purpose of our research is to create an accessible web dashboard that will present information to different experts on the latest developments in neurotechnology standards. The kind of information that we aim to get from the interview is your understanding of current neurotechnologies along with their standards, ethical practices, and resources you consult on these matters. We anticipate that the interview should take about thirty minutes.

This is a collaborative project between the Zurich University of Applied Sciences (ZHAW) and WPI, and your participation is greatly appreciated. Information from our project will be published in a publicly available academic document at the end of our term and we can share a copy of our results if you are interested. No names or identifying information will appear in any of the project reports or publications unless you give us consent to do so. We would also like to record this interview, but will not do so without your consent. Any recordings of your likeness will be kept in a Google Drive folder only accessible to our team by a password. All recordings will be deleted from personal devices after they are uploaded to this drive.

Your participation in this interview is completely voluntary and you may withdraw at any time. This also means that you can skip any questions that you want. Do you have any questions for us about this interview?

For more information about this research and the rights of research participants, you may contact us by email gr-neurodash@wpi.edu or the Institutional Review Board (IRB) Manager (Ruth McKeogh, Tel. 508-831-6699, Email: irb@wpi.edu) or Human Protection Administrator (Gabriel Johnson, Tel. 508-831-4989, Email: gjohnson@wpi.edu). Thank you very much!

Appendix B. Interview Guide for Interviews with Experts

Goal: Utilizing contacts referred by the key informants, inquire about their ideal vision for the project, provide ethical insights, and suggest documents to consult and integrate into the dashboard.

Type of Sampling: Sponsor Referrals

Interview Profiles:

- All
- Research
- Industry/Private Sector
- Regulations/Standards Board Member

Questions

1. In your opinion, what is the definition of a standard?
2. How do standards and regulations impact the clinical/research process?
3. How do standards and regulations impact the development process?
4. How do you update standards based on state-of-the-art advancements in the field (lifetime of a standard)?
5. How do you see the standards created by your organization being applied in the field?
6. How do you approach utilizing conflicting standards in your work?
7. What is your current process for finding standards and other related documents?
8. Would a centralized collection of numerous standards documents benefit you in your work with neurotechnology?
9. Present Dashboard Prototype - Short Presentation
10. Would you or others in your field benefit from having access to this dashboard?
    a. What do you like/dislike about the design?
    b. Any recommendations for workflow changes?
11. Are there standards you would like to see on the dashboard?
12. Are there any search filters you would like to see?
    a. When looking for documents any specific characteristics you look for ie. document date, publishing organization, etc.

Appendix C. All Screens of the Dashboard

Figure C1. Cookie Policy

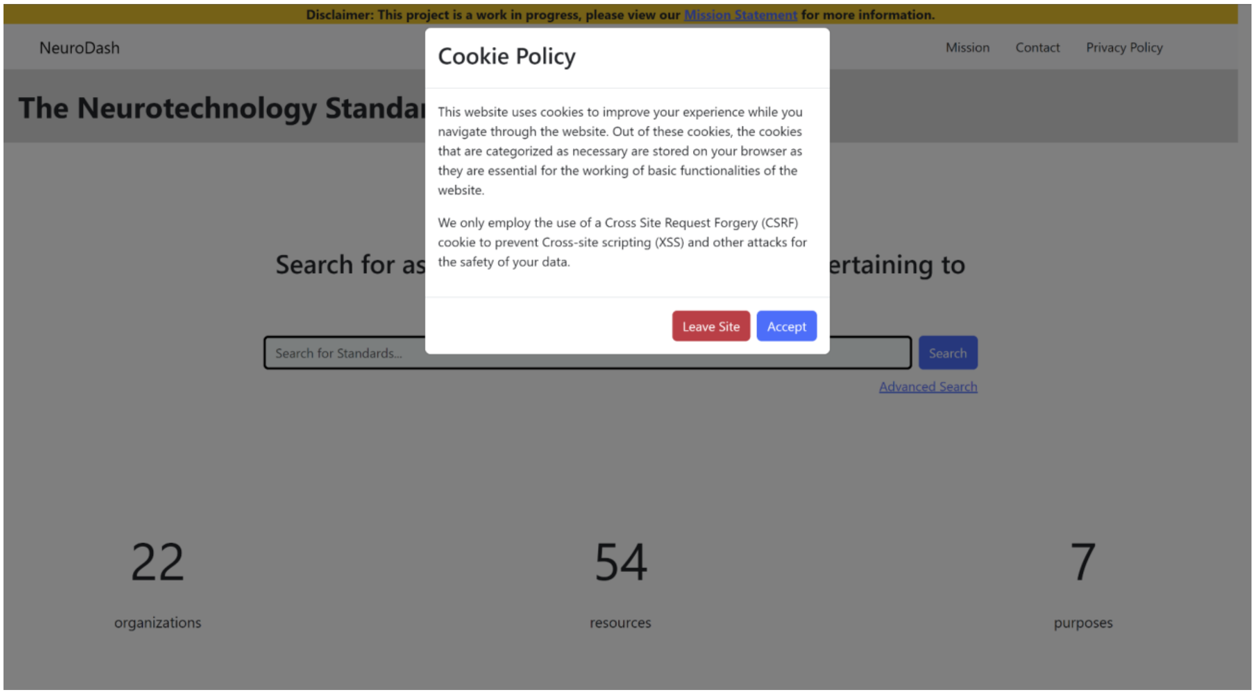


Figure C2. Home Screen

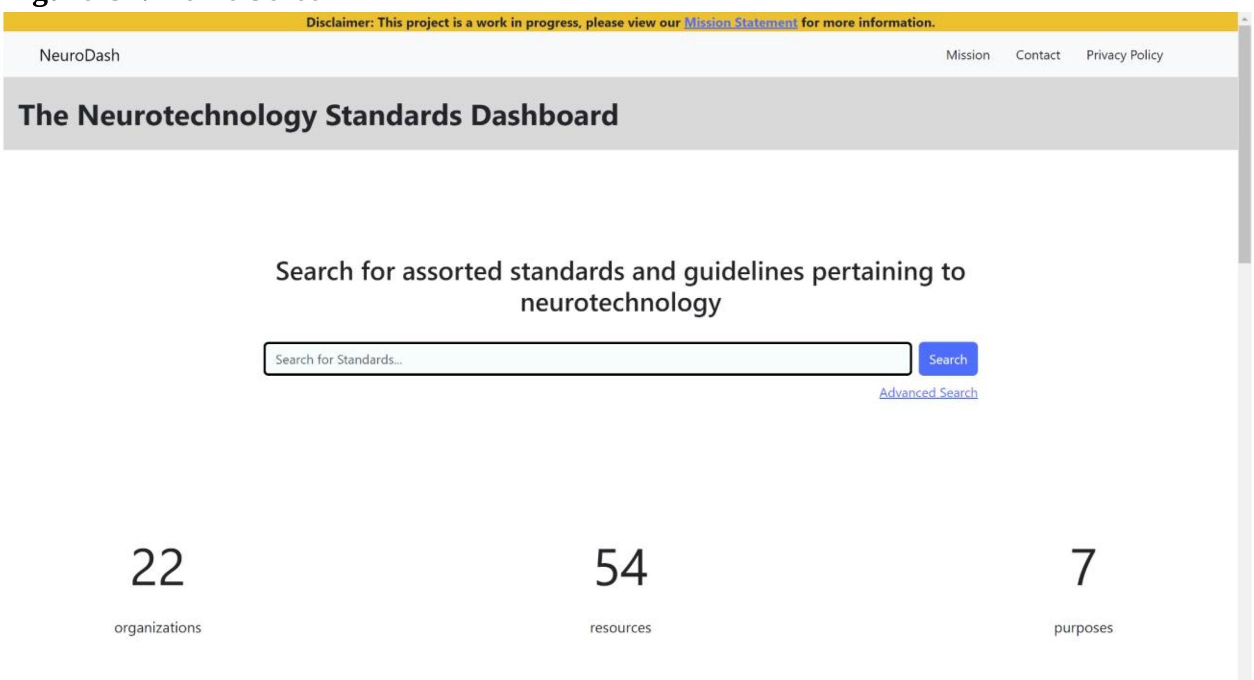


Figure C3. Organization Distribution Pie Chart

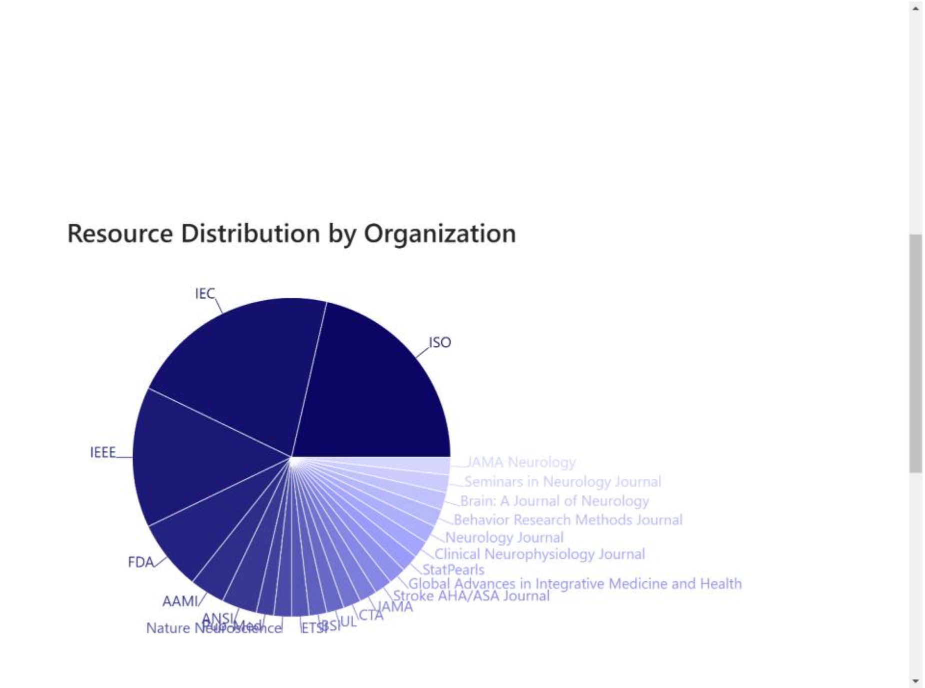


Figure C4. Pie Chart Hover Feature

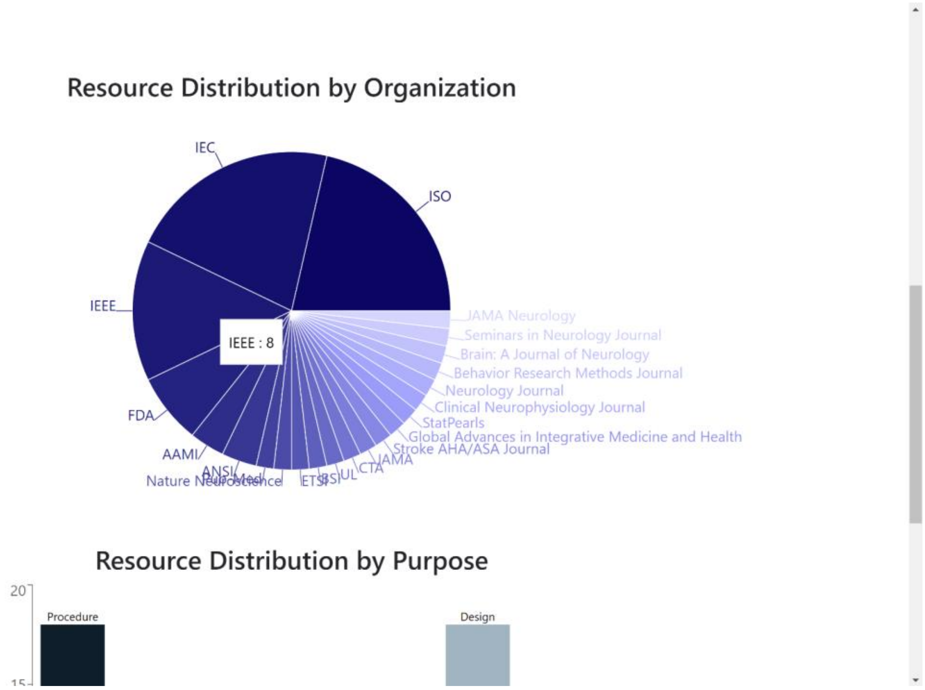


Figure C5. Purpose Distribution Bar Chart

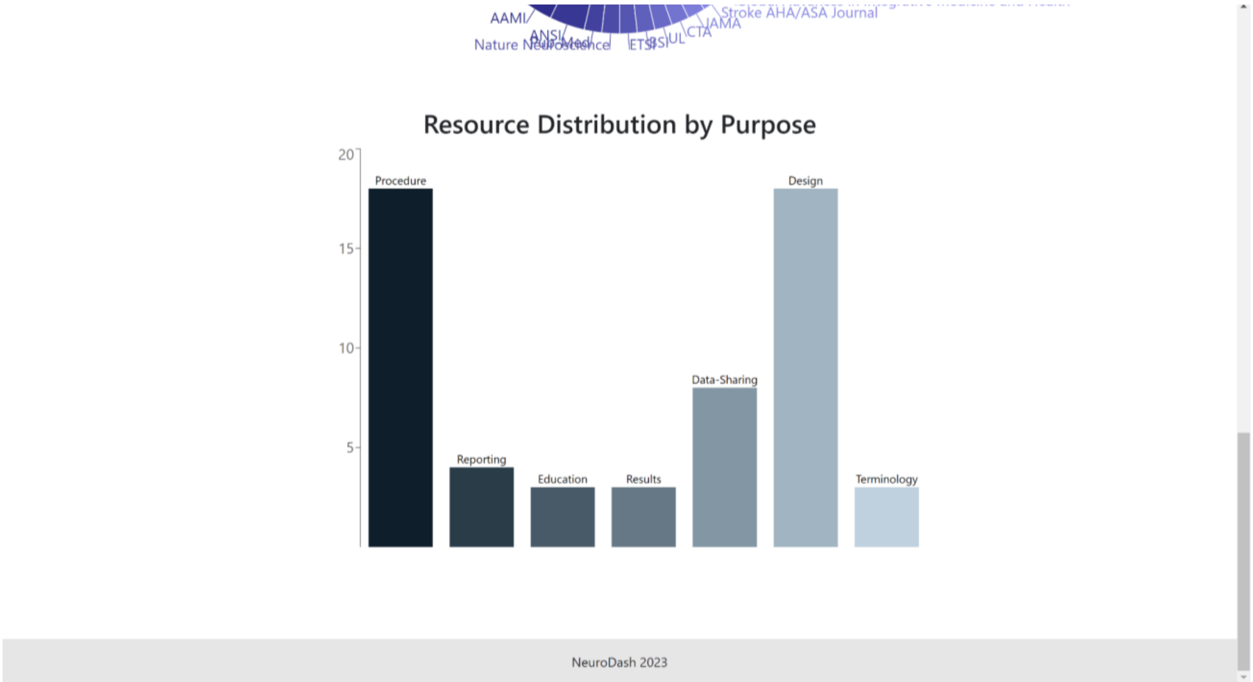


Figure C6. Bar Chart Hover Feature

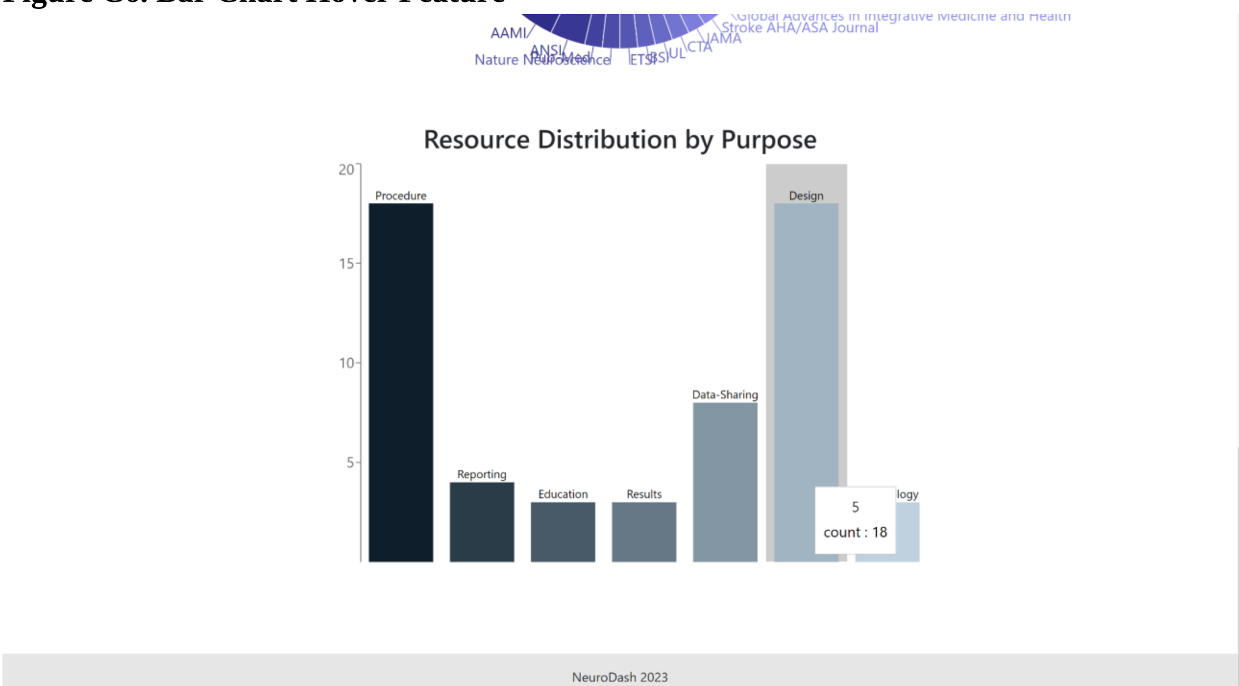


Figure C7. Mission Statement Page

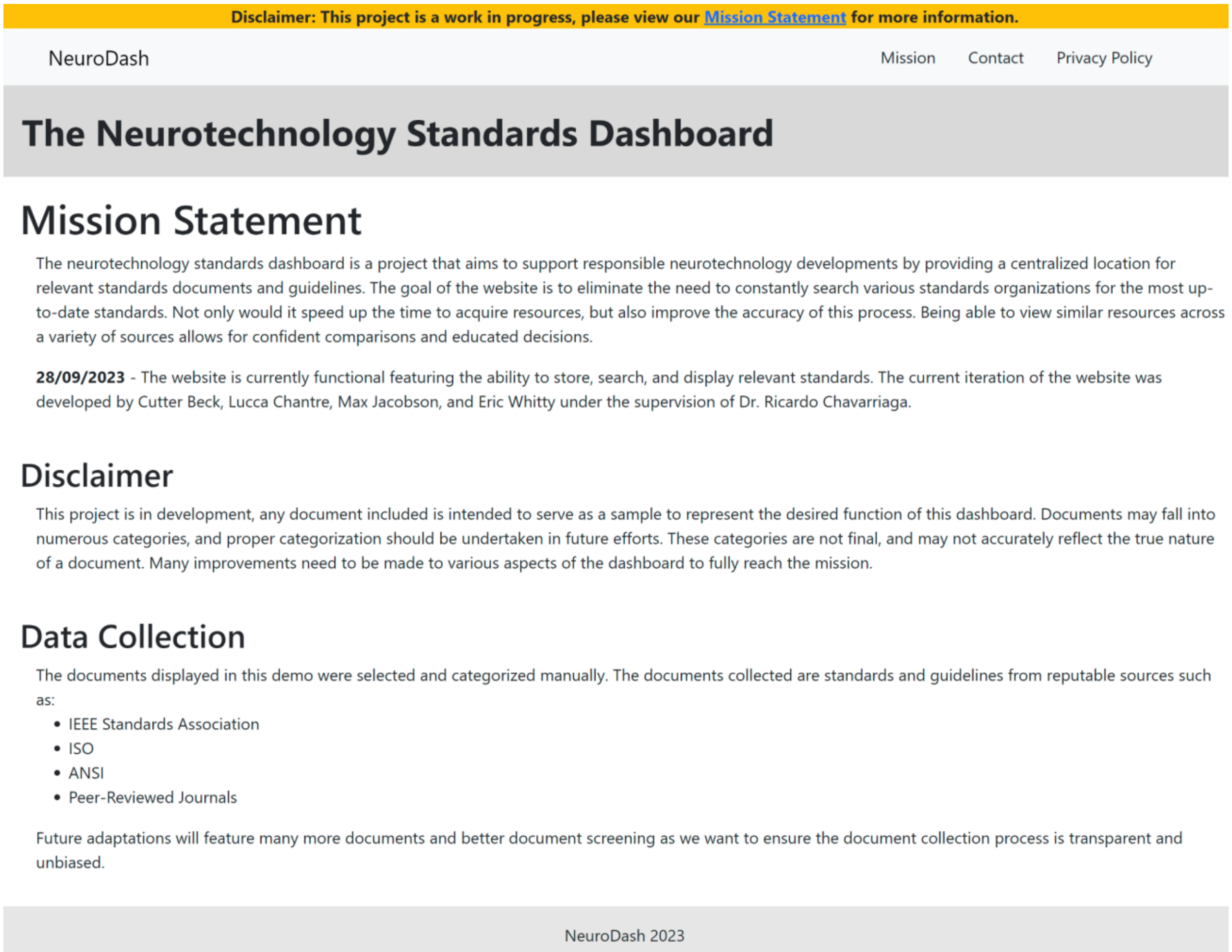


Figure C8. Contact Page

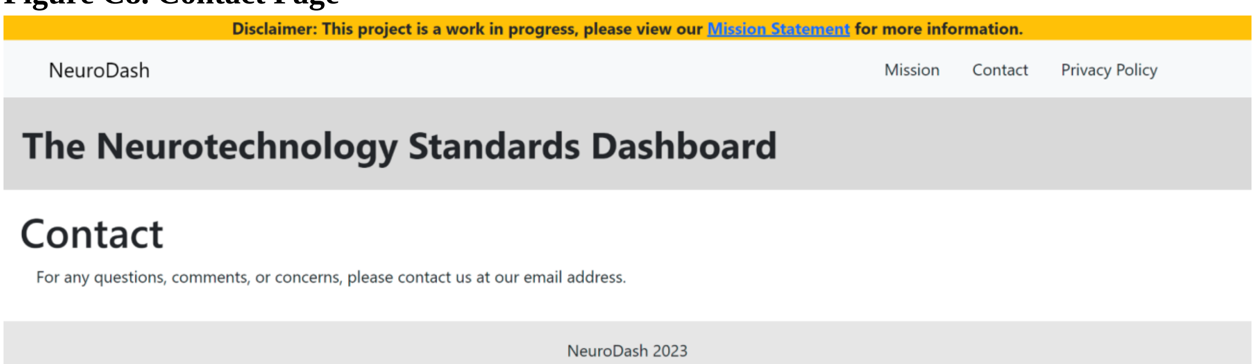


Figure C9. Privacy Policy Page (Partial)

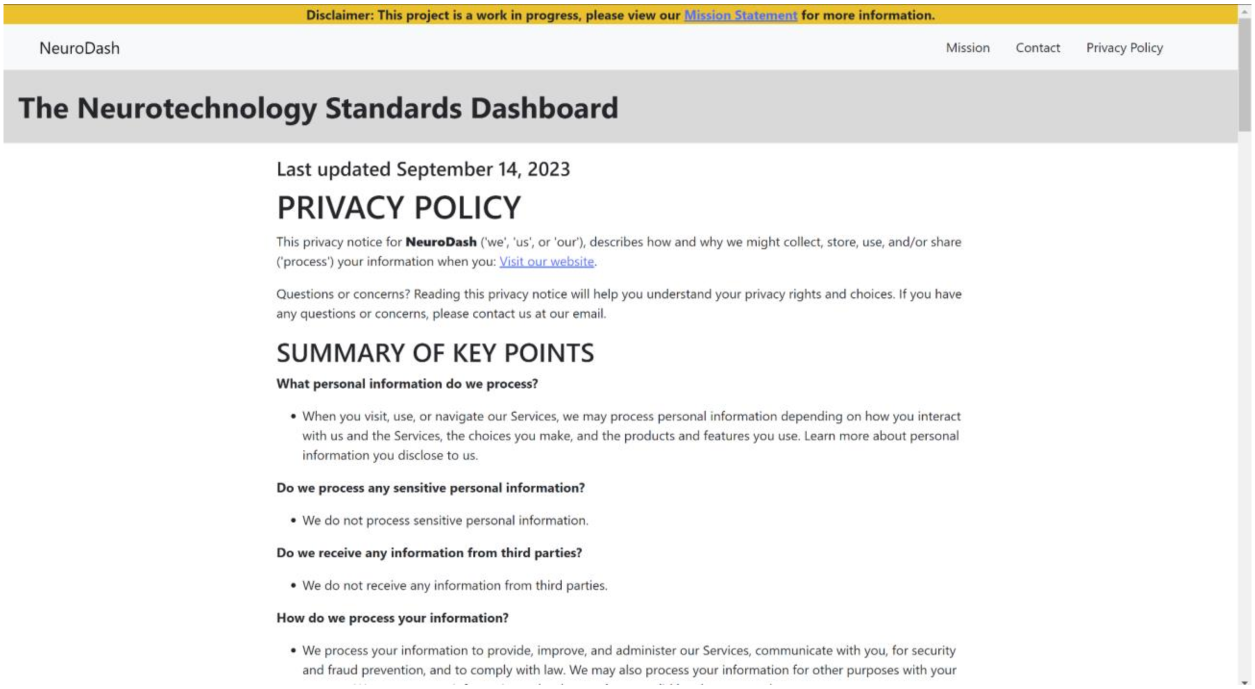
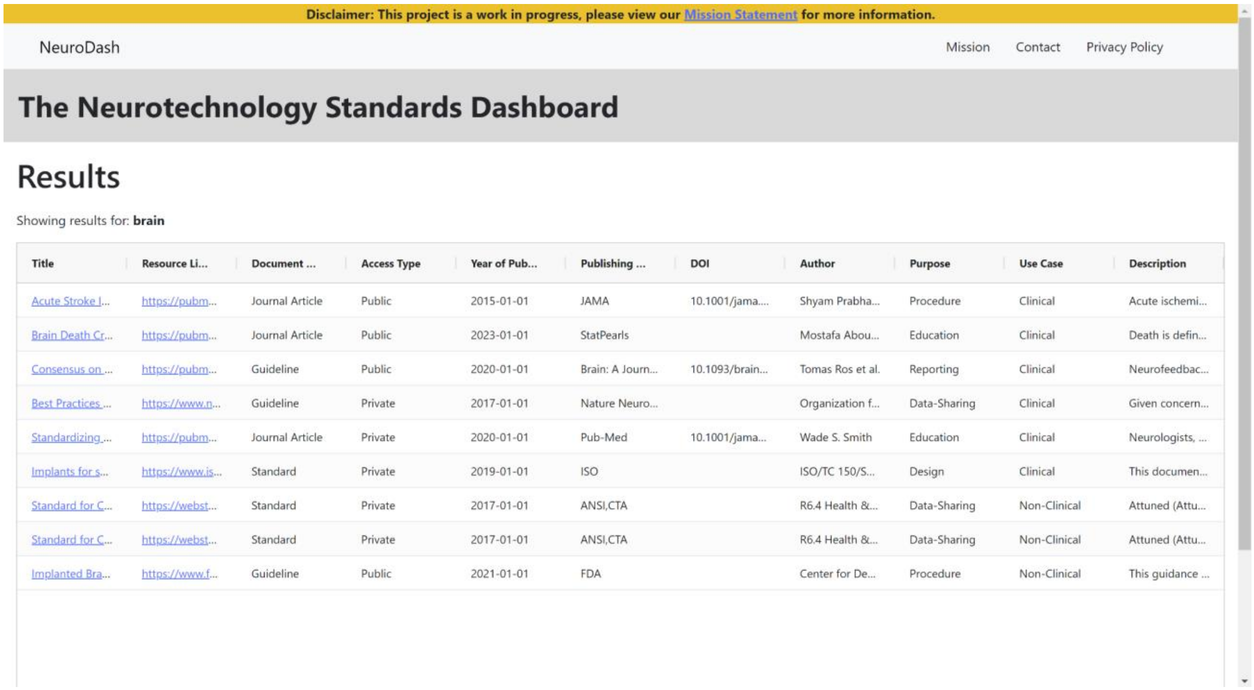


Figure C10. Home Page Search Output



Title	Resource Li...	Document ...	Access Type	Year of Pub...	Publishing ...	DOI	Author	Purpose	Use Case	Description
Acute Stroke I...	https://pubm...	Journal Article	Public	2015-01-01	JAMA	10.1001/jama....	Shyam Prabha...	Procedure	Clinical	Acute ischemi...
Brain Death Cr...	https://pubm...	Journal Article	Public	2023-01-01	StatPearls		Mostafa Abou...	Education	Clinical	Death is defin...
Consensus on ...	https://pubm...	Guideline	Public	2020-01-01	Brain: A Journ...	10.1093/brain...	Tomas Ros et al.	Reporting	Clinical	Neurofeedbac...
Best Practices ...	https://www.n...	Guideline	Private	2017-01-01	Nature Neuro...		Organization f...	Data-Sharing	Clinical	Given concern...
Standardizing ...	https://pubm...	Journal Article	Private	2020-01-01	Pub-Med	10.1001/jama...	Wade S. Smith	Education	Clinical	Neurologists, ...
Implants for s...	https://www.is...	Standard	Private	2019-01-01	ISO		ISO/TC 150/S...	Design	Clinical	This documen...
Standard for C...	https://webst...	Standard	Private	2017-01-01	ANSI,CTA		R6.4 Health &...	Data-Sharing	Non-Clinical	Attuned (Attu...
Standard for C...	https://webst...	Standard	Private	2017-01-01	ANSI,CTA		R6.4 Health &...	Data-Sharing	Non-Clinical	Attuned (Attu...
Implanted Bra...	https://www.f...	Guideline	Public	2021-01-01	FDA		Center for De...	Procedure	Non-Clinical	This guidance ...

Figure C11. Home Page No Results Page

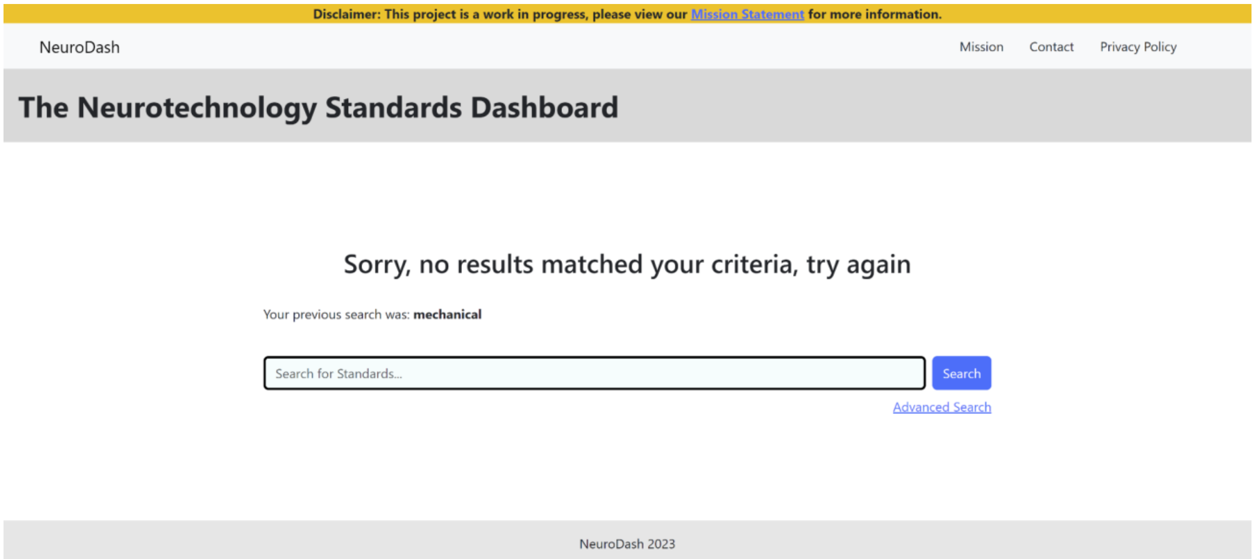


Figure C12. Results Page Tooltip Hovers

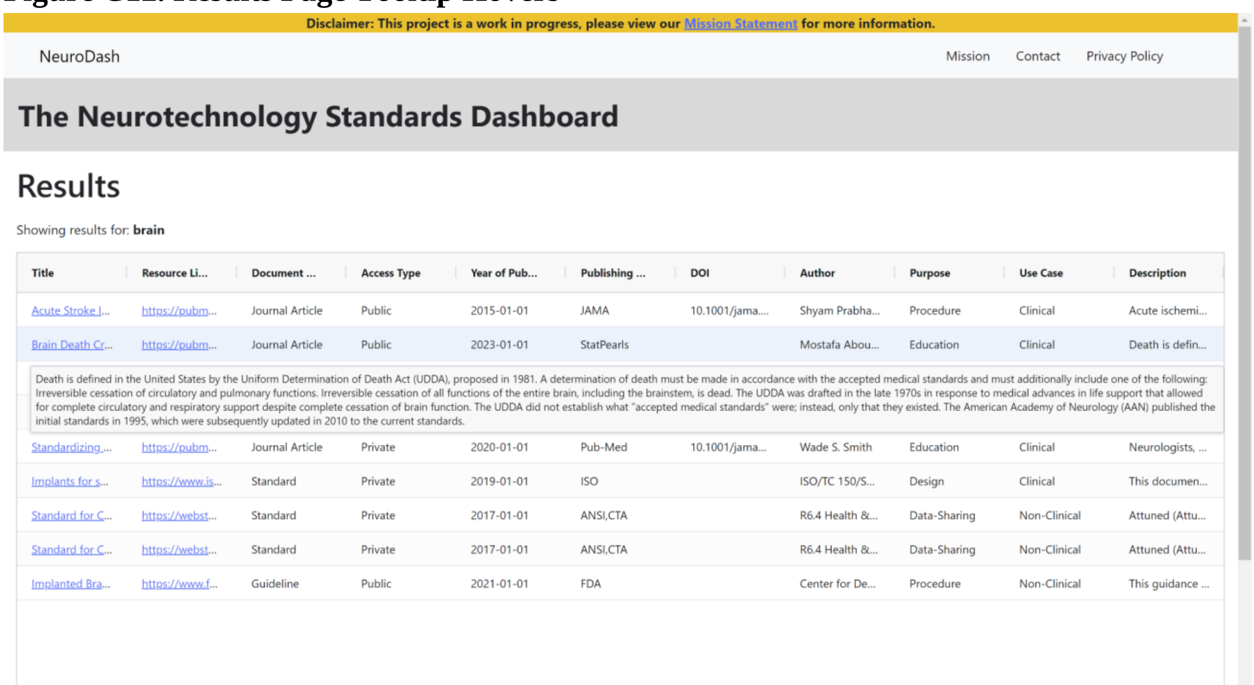


Figure C13. Results Page Column Filtering

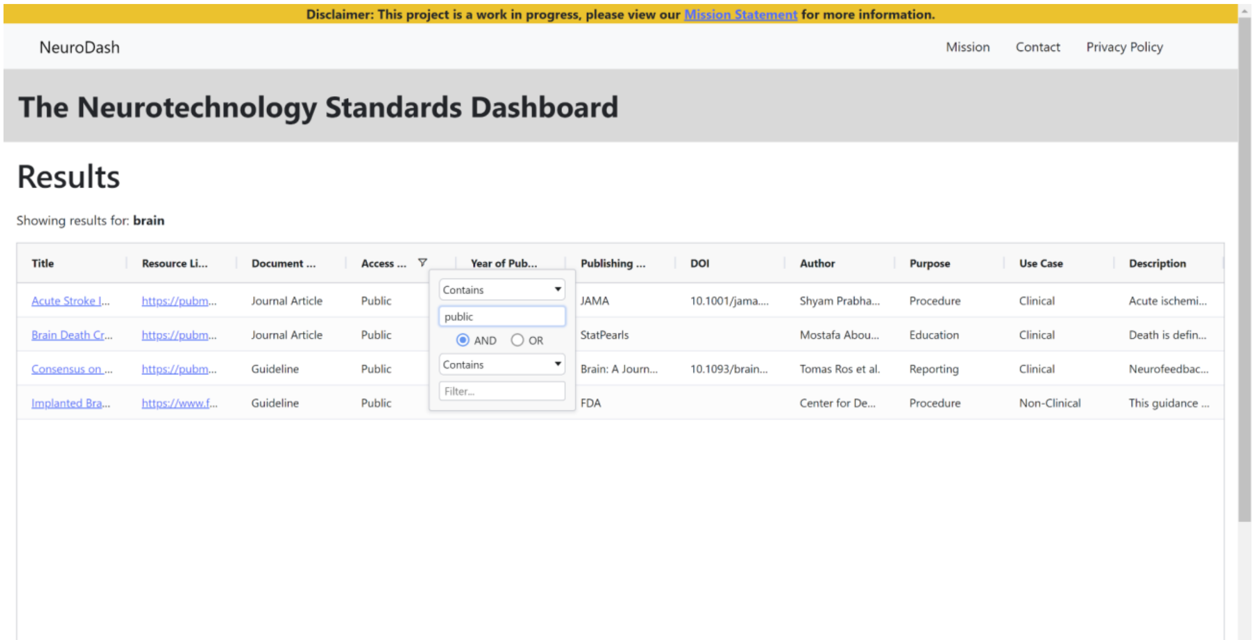


Figure C14. Results Page Column Resize and Reorder

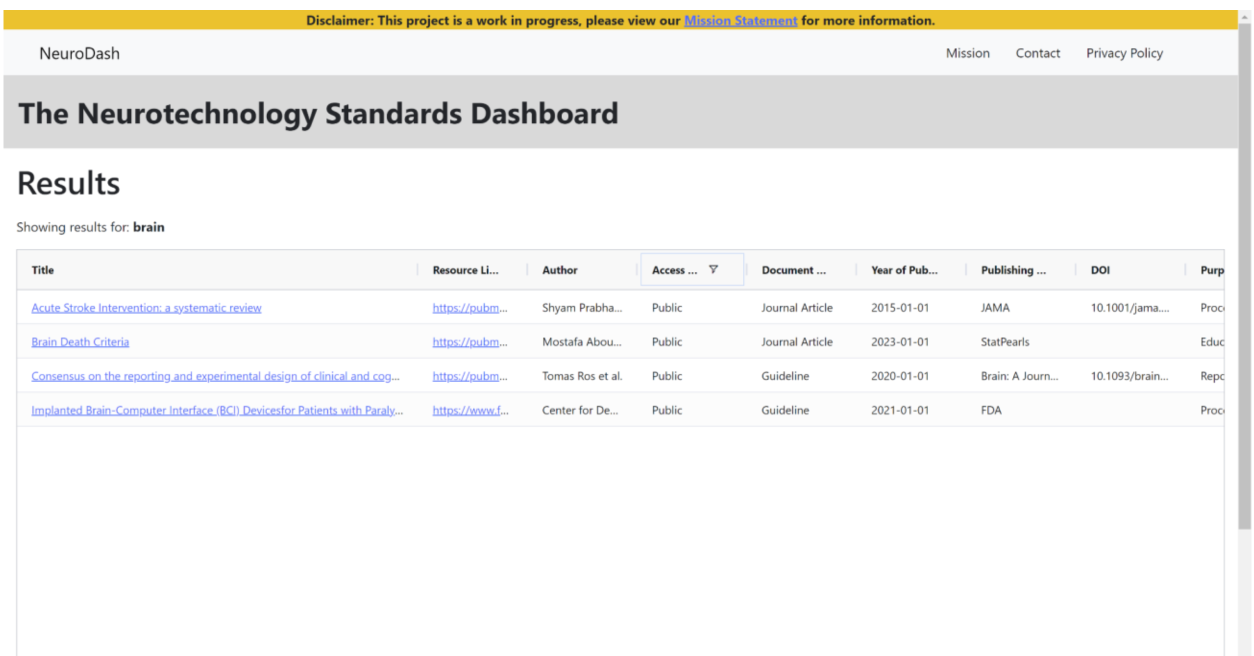
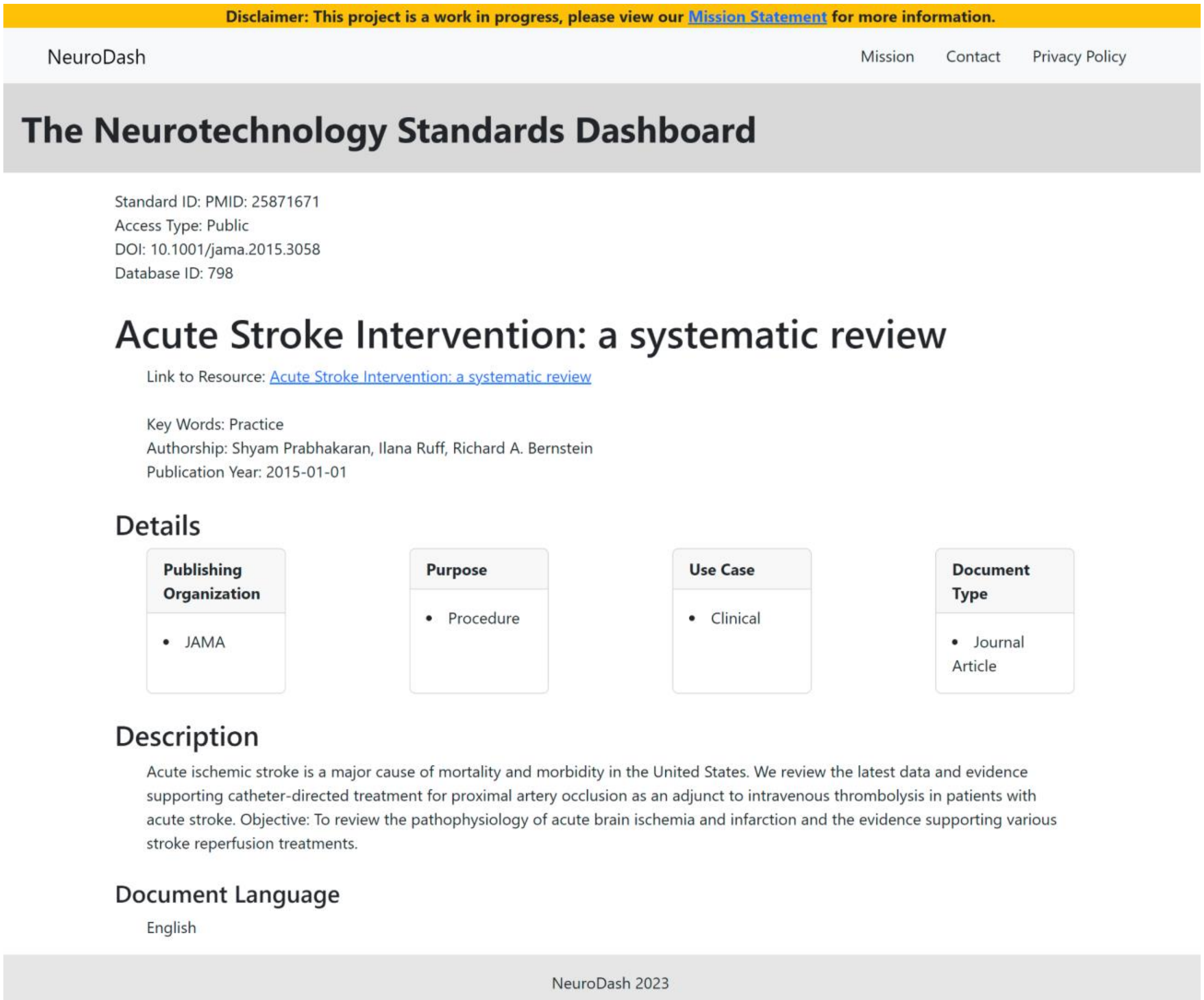


Figure C15. Example Resource Page



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The Neurotechnology Standards Dashboard

Standard ID: PMID: 25871671
Access Type: Public
DOI: 10.1001/jama.2015.3058
Database ID: 798

Acute Stroke Intervention: a systematic review

Link to Resource: Acute Stroke Intervention: a systematic review

Key Words: Practice
Authorship: Shyam Prabhakaran, Ilana Ruff, Richard A. Bernstein
Publication Year: 2015-01-01

Details

Publishing Organization
- JAMA

Purpose
- Procedure

Use Case
- Clinical

Document Type
- Journal Article

Description

Acute ischemic stroke is a major cause of mortality and morbidity in the United States. We review the latest data and evidence supporting catheter-directed treatment for proximal artery occlusion as an adjunct to intravenous thrombolysis in patients with acute stroke. Objective: To review the pathophysiology of acute brain ischemia and infarction and the evidence supporting various stroke reperfusion treatments.

Document Language

English

NeuroDash 2023

Figure C16. Advanced Search Page

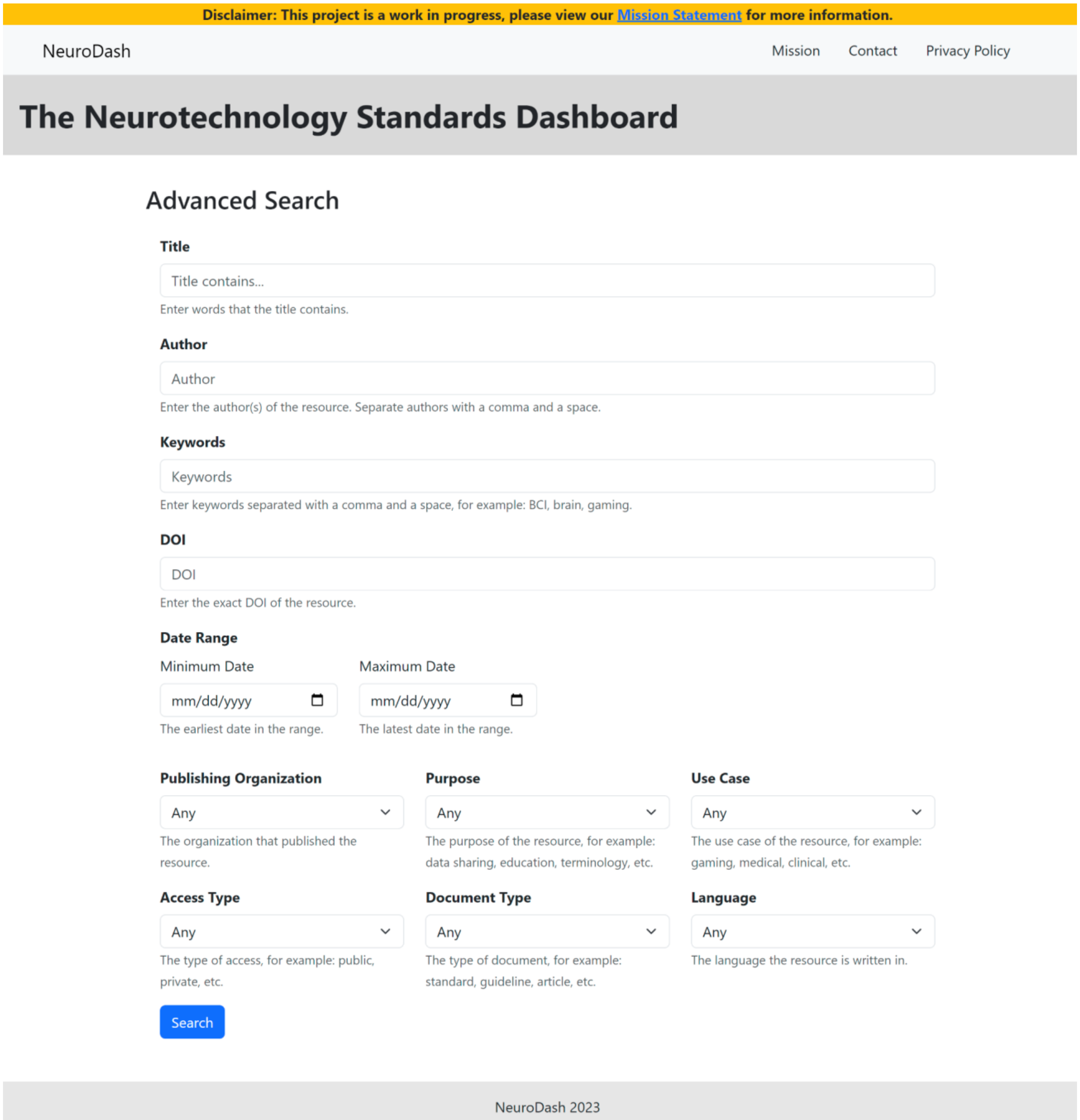


Figure C17. Partially Filled Advanced Search Form

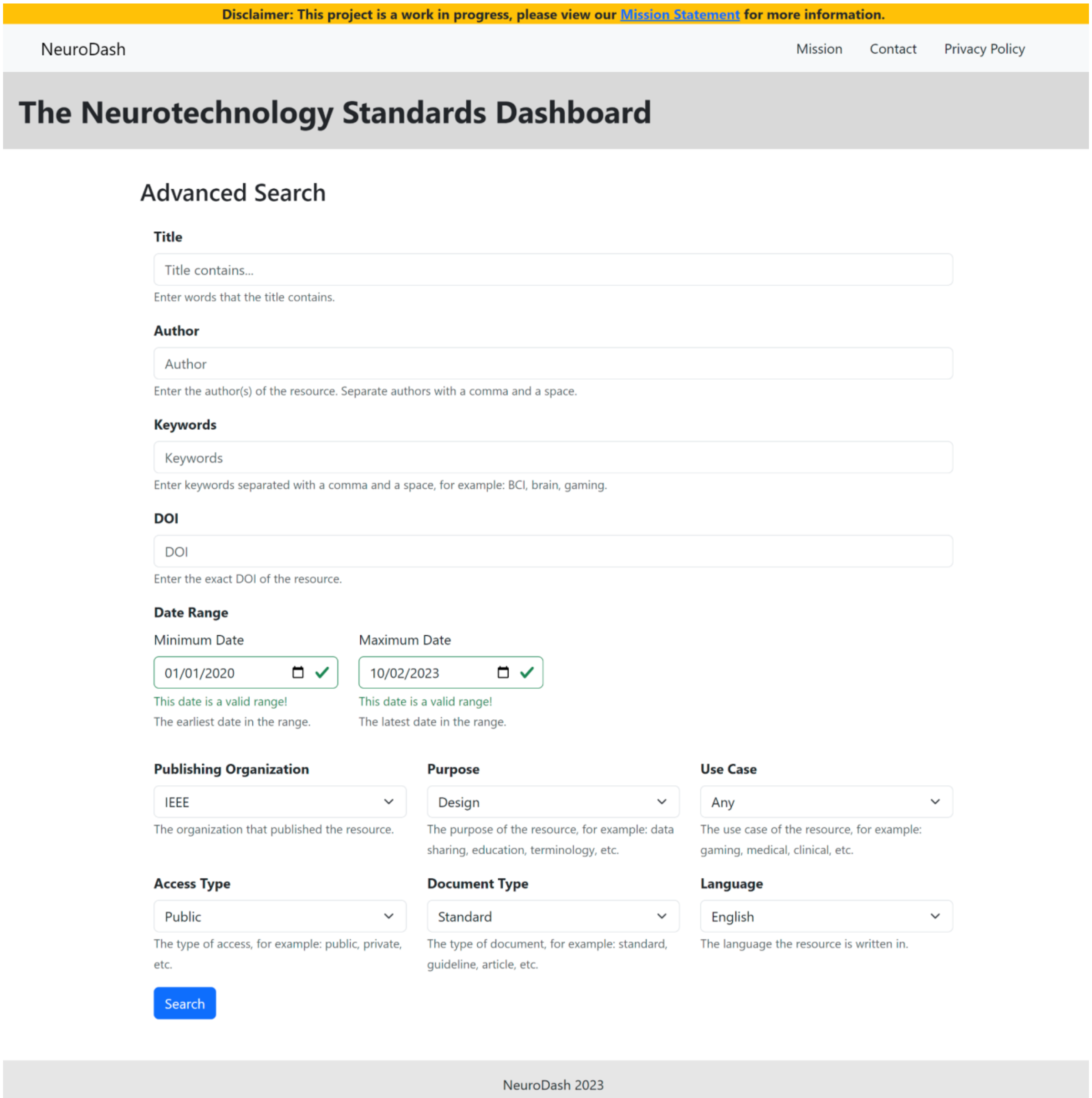
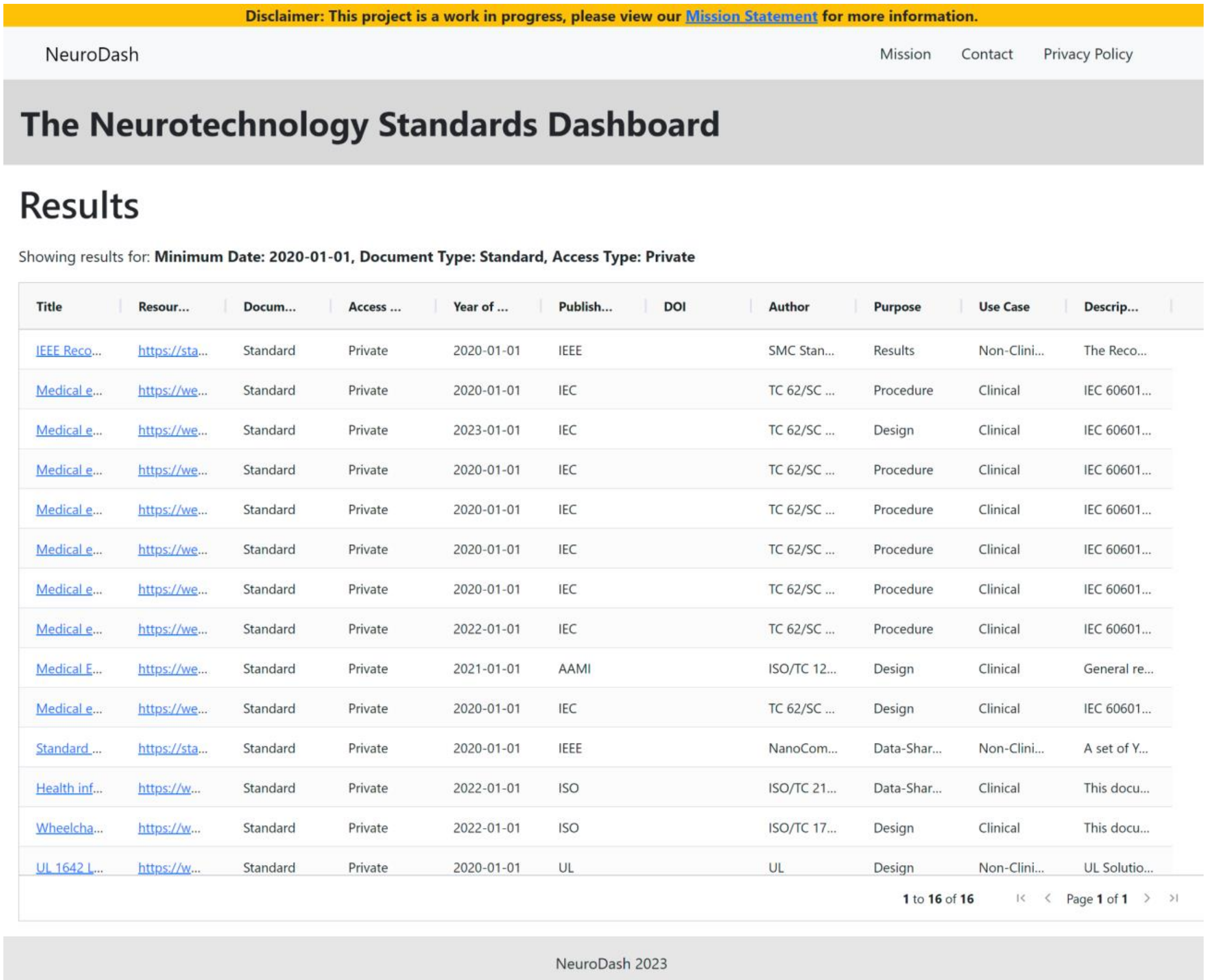


Figure C18. Advanced Search Results Page



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The Neurotechnology Standards Dashboard

Results

Showing results for: **Minimum Date: 2020-01-01, Document Type: Standard, Access Type: Private**

Title	Resour...	Docum...	Access ...	Year of ...	Publish...	DOI	Author	Purpose	Use Case	Descrip...
IEEE Reco...	https://sta...	Standard	Private	2020-01-01	IEEE		SMC Stan...	Results	Non-Clini...	The Reco...
Medical e...	https://we...	Standard	Private	2020-01-01	IEC		TC 62/SC ...	Procedure	Clinical	IEC 60601...
Medical e...	https://we...	Standard	Private	2023-01-01	IEC		TC 62/SC ...	Design	Clinical	IEC 60601...
Medical e...	https://we...	Standard	Private	2020-01-01	IEC		TC 62/SC ...	Procedure	Clinical	IEC 60601...
Medical e...	https://we...	Standard	Private	2020-01-01	IEC		TC 62/SC ...	Procedure	Clinical	IEC 60601...
Medical e...	https://we...	Standard	Private	2020-01-01	IEC		TC 62/SC ...	Procedure	Clinical	IEC 60601...
Medical e...	https://we...	Standard	Private	2020-01-01	IEC		TC 62/SC ...	Procedure	Clinical	IEC 60601...
Medical e...	https://we...	Standard	Private	2022-01-01	IEC		TC 62/SC ...	Procedure	Clinical	IEC 60601...
Medical E...	https://we...	Standard	Private	2021-01-01	AAMI		ISO/TC 12...	Design	Clinical	General re...
Medical e...	https://we...	Standard	Private	2020-01-01	IEC		TC 62/SC ...	Design	Clinical	IEC 60601...
Standard ...	https://sta...	Standard	Private	2020-01-01	IEEE		NanoCom...	Data-Shar...	Non-Clini...	A set of Y...
Health inf...	https://w...	Standard	Private	2022-01-01	ISO		ISO/TC 21...	Data-Shar...	Clinical	This docu...
Wheelcha...	https://w...	Standard	Private	2022-01-01	ISO		ISO/TC 17...	Design	Clinical	This docu...
UL 1642 L...	https://w...	Standard	Private	2020-01-01	UL		UL	Design	Non-Clini...	UL Solutio...

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NeuroDash 2023

Figure C19. Advanced Search No Results Page

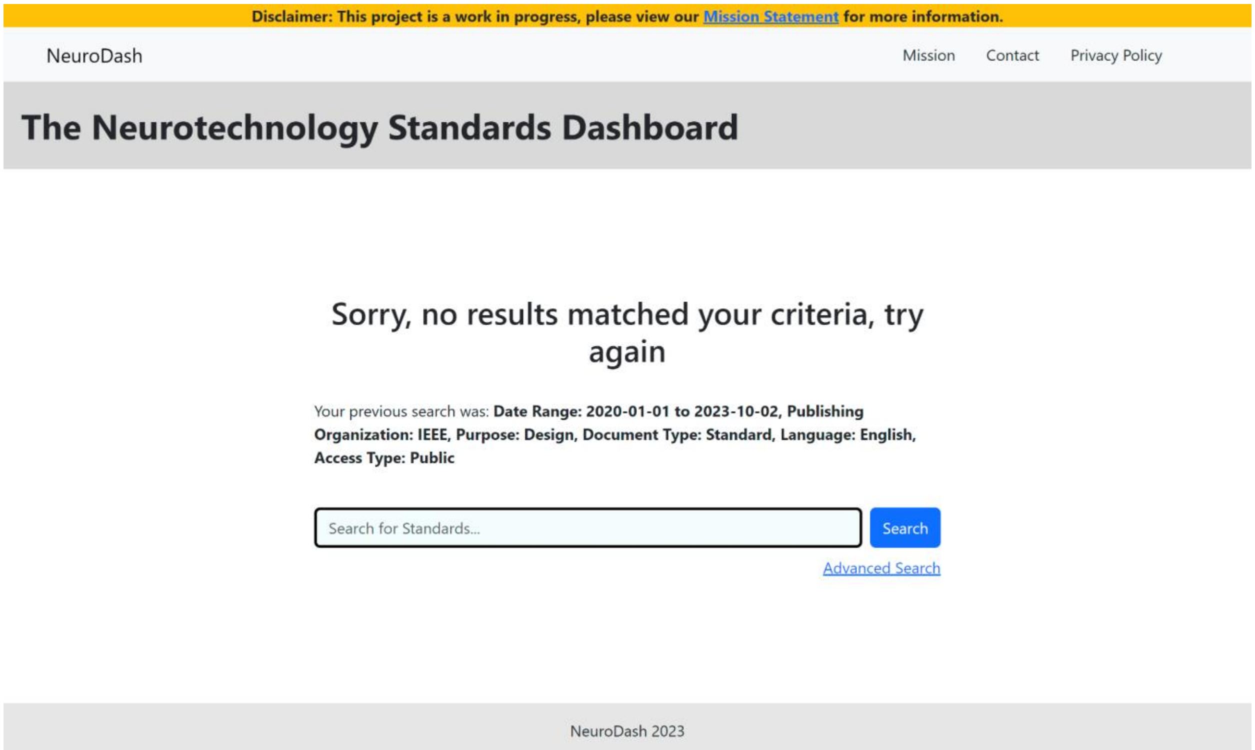

Figure C20. Administrator Interface

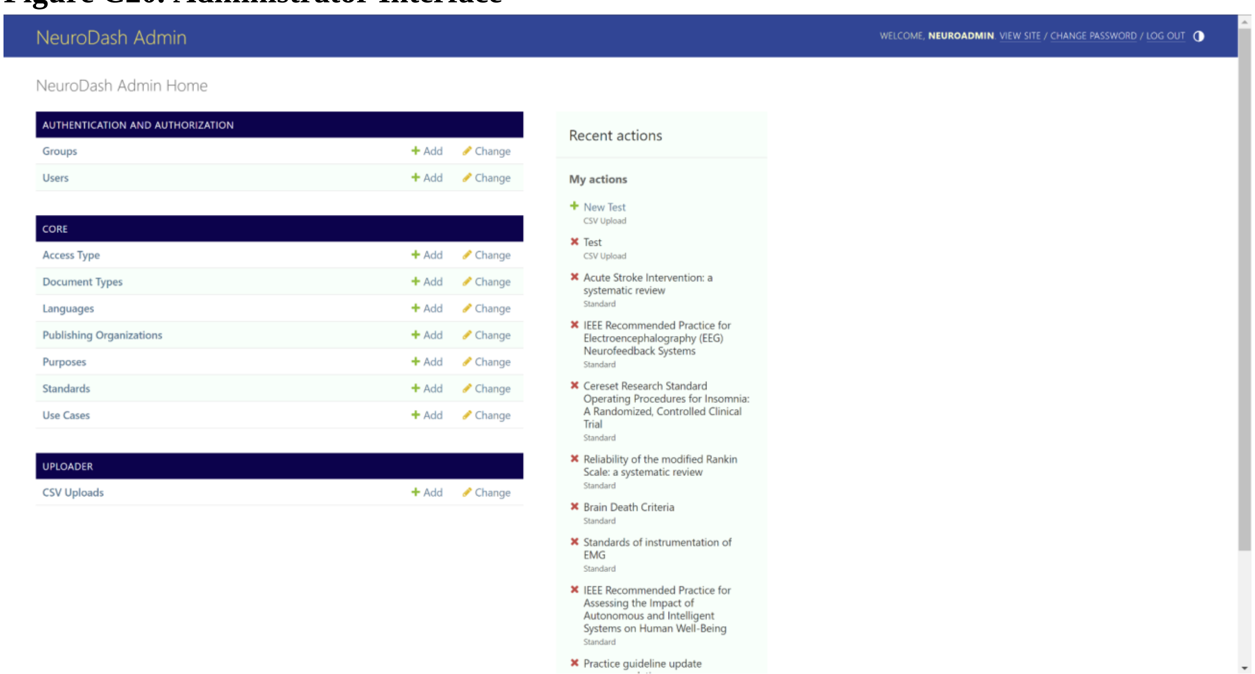

Figure C21. Standard Upload Form