The Haptiverse: A Platform for Reuse of Haptic Content

by

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Author's Declaration

This thesis consists of material all of which I authored or co-authored: see Statement of Contributions included in the thesis. This is a true copy of the thesis, including any required final revisions, as accepted by my examiners.

I understand that my thesis may be made electronically available to the public.

Statement of Contributions

This thesis contains content in which I have first-authored that has been published by IEEE in the 2021 IEEE World Haptics Conference (WHC). The Work in Progress (WIP) paper is the following:

- P. Samithamby, B. R. Joshi, H. Seifi and O. Schneider, "Towards the Haptiverse: An Online System for Sharing Haptic Content," 2021 IEEE World Haptics Conference (WHC), 2021, pp. 867-867, doi: 10.1109/WHC49131.2021.9517175.

Bibhushan Joshi, Nikesh Kumar, Andy Wu, Anchit Mishra and Tanish Shah developed the high-fidelity prototype of the Haptiverse that has been used for Experiment 2. Figures of the high-fidelity prototype can be found in the Design chapter of this thesis, under the section *High-Fidelity Prototype*.

This thesis also contains mission statements that Oliver Schneider and Hasti Seifi have helped create. The mission statements can be found in the Design chapter of this thesis, under the section *Creating A Mission Statement*.

Abstract

Research into haptic technology has accelerated over the past decade, producing more devices and content than ever before. However, due to the innate diversity of its hardware and the sense of touch itself, existing haptic experiences are limited to a specific physical technology or interaction modality. To remedy this, we introduce the Haptiverse, a platform for reuse of heterogeneous haptic content. The collection will be designed to internally motivate hapticians, who are designers, researchers, or developers of haptic experiences, to share their work with the global haptics community. We implement design features to target each basic psychological need in order for users to feel internally motivated to continue to share their work using the collection. Our results show that there was a positive influence in users' perceived competence when interacting with a multi-step form to upload content. Users' perceived relatedness and autonomy were also positively influenced after reading the Haptiverse's mission statement. In addition, novice hapticians reported higher levels of perceived relatedness after reading a mission statement that incorporated both autonomy and relatedness intrinsic goals. We present a minimum viable product of the Haptiverse and design recommendations to further support hapticians when sharing haptic content.

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Chapter 1

Introduction

Haptic technology can enrich user experience through touch feedback. The technology ranges from simple vibration notifications on smartphones to mid-air touch interactions in immersive gaming [1, 2]. Its ability to create realistic physical experiences in virtual environments has enhanced home entertainment and immersive gaming, in addition, the technology is crucial in accessibility and motor skill training [3, 4]. Although interest in haptics continues to grow, the field is relatively novel and faces a number of challenges such as the adaptability of existing haptic interfaces and high initial costs [5]. Hapticians, who are creators of haptic experiences and platforms, struggle to make new content as it remains a time-consuming and frustrating process [3].

Hapticians find it challenging to reuse each other's work, as haptic content is exceptionally diverse. Haptic content varies not only in its physical technologies but in interaction behaviours and the sense itself [6, 7]. For example, the Haply pantograph and Phantom Omni are haptic devices that support force feedback, however, the Haply pantograph can only support two Degrees of Freedom (DoF) movement whereas the Phantom Omni can support six DoF [2, 8]. Haptic experiences are often bound to the hardware of the device and expected use case, making its design highly individualized. Due to the case-based nature of haptic design, existing repositories that host haptic content are segregated by their hardware and interaction purposes (e.g. VibViz is a library of 120 vibrotactile icons, Penn Haptic Texture ToolKit is a repository of 100 haptic textures) [9, 10]. Existing haptic repositories are also substantially smaller than databases supporting other modalities. For example, the stock photography website for ShutterStock hosts over 300 million images in its database [11]. Access to a collection of existing ideas can also help hapticians build off existing knowledge as opposed to constantly creating haptic designs from scratch. The

reuse and remixing of existing ideas is a common practice that is often beneficial to learning and outcomes [12, 13], however, tools to assist hapticians with this task are limited [1].

Variations of the haptic design process may differ based on experience level, but sharing knowledge with other designers can be incorporated throughout multiple stages [7]. Sharing knowledge can include giving informal feedback to sharing completed haptic experiences that can be reused to create new designs. Studies show that software teams in particular can benefit from sharing and reusing designs [14, 15]. In order for hapticians to experience the benefits, they need to first be willing to share their content with others. Not only is a central platform needed to support hapticians sharing their work, but they also need to feel motivated to do so.

Hapticians need to feel internally motivated to share their work. Ryan and Deci identify a self-determination continuum for various types of motivation. They describe the most internalized motivation, referred to as intrinsic motivation, as the, "inherent tendency to seek out novelty and challenges" [16]. Individuals thrive in this state as it is the most innate. While the ultimate goal is for hapticians to feel intrinsically motivated, experiencing pure enjoyment each time content is shared is unrealistic to achieve, therefore supporting hapticians feel a more internalized motivation, such as identified or integrated regulation is more reasonable objective. External motivators, such as tangible rewards, do not ensure prolonged motivation and has been found to impact performance and creativity [17]. Hence fostering hapticians' internalized motivation to share their work can positively influence the quality of the haptic content they create. In order to enhance this, three basic psychological needs must be satisfied [16].

Therefore, the question is, how can we support hapticians of all experience levels when sharing content? In order to answer this question, we conduct a literature review of what creators in other domains use to share their work and how we can transfer this knowledge to the field of haptics. We also evaluate existing solutions for sharing haptic content and identify where hapticians need help. In efforts to further progress the field of haptics, we introduce the Haptiverse, an online collection that supports the sharing of heterogeneous haptic content.

In order for the Haptiverse to truly be adopted and receive a critical mass of users, the next question remains, can an online collection of heterogeneous haptic content internally motivate users to share their work? We incorporate a mission statement and a multi-step online form for uploading content to satisfy the basic psychological needs identified by Ryan and Deci in order to influence a user's internal motivation [16]. The goal of the mission statement is to help connect hapticians and determine what inspires them to share their work. The online form for uploading content will help creators of diverse haptic

content determine what information is required to transfer knowledge in order for users of all experience levels to understand and replicate their work.

1.1 Contributions

While haptic collections exist, they are underutilized as they are focused on specific research projects or devices, and are difficult to find. To remedy this, we propose relocating all haptic content in a singular location, regardless of device or author. This thesis contributes an initial user interface design of the Haptiverse, an online collection for the reuse of heterogeneous haptic content. We also contribute results from an anonymous survey and observational study that evaluates users' basic psychological need satisfaction when interacting with the platform. We suggest specific design elements within the Haptiverse that can positively influence a user's perceived competence, relatedness and autonomy, in turn supporting a more internalized motivation. By evaluating specific design elements that have the potential to support users' basic psychological needs, we predict that users will be internally motivated to share work using the novel collection, and encourage more widespread utilization of the system.

This work presents several user interface designs using medium- and high-fidelity prototypes and future design implications for the Haptiverse that can influence a user's basic psychological needs when sharing content.

1.2 Outline

This thesis is organized in the following chapters:

- Chapter 2 provides an overview of the current state of haptic technology, existing haptic repositories and the importance of incorporating knowledge sharing and human motivations to the field of haptics.
- Chapter 3 outlines the design of the Haptiverse and presents prototypes.
- Chapter 4 discusses the first experiment used to evaluate the Haptiverse and its results.
- Chapter 5 discusses the second experiment used to evaluate the Haptiverse and its results.

- Chapter 6 is a conclusion of this thesis and details of future work.

Chapter 2

Background and Related Work

2.1 Current Haptic Design Process

The field of haptics, referring to the study of the sense of touch, bridges a variety of fields ranging from psychology to computer science [4]. Haptic feedback has the ability to enhance the virtual world through its unique bidirectional flow of information, which would have otherwise been limited spatially and temporally from visual and/or audio cues alone [18]. While the importance of haptic feedback in immersion and accessibility is undeniable, the field remains in its infancy due to a number of barriers such as the scarcity of haptic design tools and guidelines [2, 4]. Schneider et al.[3] highlight the differences between haptic technologies and with human preferences and perception of touch. Haptic design is highly individualized, making extrapolation from existing platforms and experiences a near impossible process.

MacLean et al.[7] identify four fundamental haptic design activities: browsing, sketching, refining and sharing. Browsing refers to storing, viewing and organizing existing examples for inspiration. This is a common practice in many fields as ideas are not materialized spontaneously. Ideas are often the result of relevant knowledge and by building off existing content, more unique solutions can be realized [12]. Sketching is also common in design as it can convey complex ideas in a digestible fashion. The last activity, sharing, the main focus of this thesis, involves distributing, collaborating, receiving feedback, and reusing existing examples [7]. Sharing is imperative to the advancement of haptic technology as sharing multiple designs can improve collaboration and the refinement of designs [15]. Sharing designs can also create a wider set of differing ideas leading to more innovative solutions [19].

The haptic design process is especially important for novice hapticians as Hasti et al. [2] found that novices often skip essential activities in the haptic design process and struggled to communicate when collaborating. With supporting tools and guidelines lacking, effectively incorporating the four haptic design activities becomes more of a challenging task to new designers. Experts can help breakdown the innate complexities of designing haptic technology by identifying categories that novices can recognize and ultimately guide them to creating haptic designs [20]. In order to elicit this feedback, a mechanism for sharing existing haptic designs and new ideas needs to be created.

2.2 Existing Haptic Collections

Haptic content is fragmented online as minimal haptic galleries exist and are small-scale. As discussed in the previous section, designing haptics is a difficult task and requires an array of examples [21]. Schneider et al. [19, 22] states that there is a lack of transparency and replicability of haptic technology. Parameter details and modifications are also limited, resulting in hapticians recreating a haptic experience from scratch. As the field of haptic technology becomes more established, it is imperative that collections of haptic experiences expand and further support the needs of hapticians through intentional user interface (UI) design.

CHAI3D is a C++ simulation framework with open source libraries for haptic computing. The libraries support three-, six- and seven-DoF devices. While documentation and examples are available, the library is focused on a framework for creating novel haptic experiences rather than showcasing and sharing existing solutions [21].

Haptipedia is another haptic collection, a public online taxonomy for exclusively force-feedback devices. The collection is focused on hardware and has a number of categories for each device such as cost, robustness and portability [1].

Libraries specific to vibrotactile (VT) icons have gained traction as the process to create vibrotactile cues is arguably more linear. Choi et al. [23] states that two decisions must be made when incorporating VTs: actuators and how to spatially arrange them. Commercially available actuators are now easily found and incorporated, however, platforms to create and/or view existing VT icons remain small in scale and scattered amongst the web. VibViz is a platform with 120 vibrations characterized by metaphor and other key metrics. While its transparency in parameters is exceptional, its size and restriction to a singular modality presents limitations to hapticians [23]. Syntact is another platform focused on VT icons, however, rather than hosting a collection of pre-made VT icons, the platform consists of a haptic rendering framework to create and edit icons [24].

Online collections of haptic textures also exist, such as The Penn Haptic Texture Toolkit (HaTT). The collection hosts 100 haptic texture and friction models and was originally created for hapticians to validate their texture models [10]. However, the collection presents similar limitations to VibViz.

A repository for the Haply Development Platform, a force-feedback software and hardware platform, is available to the public online and it was initially created to support novice hapticians. Providing the documentation required to build the device and produce haptic interactions proved to be vital to novices as they tended to ignore other online resources when using the device and rarely iterated on their designs [2]. While the online repository for the Haply Development Platform is quite thorough, it is solely designed for the device and made by the creators of the device, limiting content from external resources [25].

Conversely, popular non-haptic multimedia online collections include YouTube, Instagram, Shutterstock, and Thingiverse. While the former three are technically not device driven, they all promote the sharing of new content. YouTube and Instagram have monopolized the social content space with their simplicity in uploading and sharing images and videos through their applications. Their easy preview and sharing abilities have captivated millions of users and their popularity continues to grow [26, 27]. Shutterstock's large collection of high quality images and appealing UI has generated over 1 billion downloads from users [11]. Lastly, and arguably most relevant to the field of haptics, Thingiverse, supports 3D printing with its simple search and remix mechanisms. Its standardization of varying "things" through its clean UI makes its collection more inviting to novices in 3D printing [28, 29]. The qualities of each of the applications listed above can inspire the field of haptics to further progress.

2.3 Importance of Knowledge Sharing to Overcome Barriers

Sharing knowledge is imperative to the advancement of haptic technology as it involves a challenging design process that is software- and hardware-intensive [21]. It has been hypothesized that the field's small size is due to the lack of coordination of knowledge between different haptic communities [30]. The diversity of its devices also creates challenges to adapting a more widespread haptic vocabulary as categorizing the technology has remained relatively high-level [31]. Attempts have been made to create a more expansive list of categories, but only for specific types of hardware [20]. However, ensuring all resources have been referenced when creating these new categories is difficult to do in a fragmented

ecosystem of disparate data.

Studies have revealed that reusing existing designs can improve sharing and innovation in software teams [14, 15]. Having experts share their knowledge is especially important as it can be tacit, making it hard to articulate [32]. Ensuring a variety of formats are used to share information can overcome this. Explicit and tacit knowledge are complementary; therefore, both should ideally be supported [33]. Explicit knowledge, that is information that can be expressed in formal language, is essential for geographically distributed teams [34].

Experience levels can also dictate how to effectively share knowledge. In haptic design, novices are often presented with mature tools that require technical domain knowledge [2]. There is a large knowledge gap between experienced and aspiring hapticians [35]. Literature in User Experience (UX) gives insight into effective design elements to present data to non-experts, such as familiarity, brief content, and appealing layouts [36]. Tagging mechanisms can assist in bridging the gap by reducing knowledge vaporization of experts. The tags can use familiar language to help novices better understand the complexities of haptic technology [34].

Open source software communities, such as GitHub, are rich in knowledge sharing. Users share information freely and engage in collaboration in hopes of creating new and improved solutions [37]. Contributions to these communities are often highly dependent on individuals with the most up-to-date knowledge in the field. These individuals, referred to as lead users, are responsible for novel solutions, and can assist novices in getting more involved with the community [38]. Open source software platforms also provide ways to measure the amount of knowledge that is shared by counting posts and other forms of interactions between knowledge seekers and knowledge providers [39].

The longevity of open source software communities have also been linked to their collective identity. Studies have found higher user retainment in more niche communities. However, the more unique the community, the larger the barrier to entry can be for novices [40]. Skill diversity is a knowledge sharing driver, therefore, niche communities can benefit from having a more inviting environment so that more knowledge can be shared [41]. A balance of creating a clear community identity and having it be inviting to newcomers is essential to the longevity of open source platforms.

2.4 Self-Determination Theory (SDT)

Motivation is important to consider in the context of haptic technology as it can forecast both product sustainment and stakeholder satisfaction. Human-centred design emphasizes the importance of users' intentions. While usability is vital, a product's usage is not solely predicted from this alone but by what it means to its users and the emotions it evokes [42]. Human motivation is a popular theme in psychology as it inevitably produces something that is strongly valued in society. Human-computer interaction (HCI) games research has also taken to the theory and has increasingly incorporated it due to its success in a variety of other disciplines [17]. Ryan and Deci's SDT is a differentiated approach that acknowledges humans' innate tendencies towards personal growth and behavioural self-regulation. It identifies motivation as a spectrum; amotivation involves having no intention to pursue a specified goal, extrinsic motivation is driven by external incentives, and intrinsic motivation is the most internalized type of human motivation [16].

Ryan and Deci present a self-determination continuum to describe different types of motivation. Amotivation and intrinsic motivation can be found at either ends of the continuum. As an individual shifts to the right of the of the continuum, they experience a more internalized motivation. Intrinsic motivation is best described as the curiosity and enjoyment that children feel when attempting new tasks. An intrinsically motivated individually completes a task out of pure enjoyment. Other types of internalized motivation include identified regulation and integrated regulation, which can be found off to the right of the centre of the continuum. While these motivations are a part of the extrinsic motivation spectrum, they have elements of internal motivation. Identified regulation acknowledges the personal importance of completing a task and integrated regulation finds alignment with the importance of completing a task and one's own values [16].

In order to foster internal motivation, Ryan and Deci identify basic psychological needs that should be satisfied: autonomy, competence and relatedness. Autonomy refers to an individual's volition to perform a task, competence is feeling confident in one's skills to complete a task, and relatedness refers to the social connection felt with others. All three needs are essential for personal growth and self-regulation [43, 44].

SDT has been used in HCI research in a variety of capacities. The theory contains six mini-theories, with one of them being the Basic Psychological Needs Theory (BPNT). BPNT emphasizes the importance of satisfying autonomy, competency and relatedness in order to influence one's intrinsic motivation. Hassenzahl et al. [45] found the fulfillment of universal psychological needs to be a major driver of positive experiences with interactive technology. HCI papers published in CHI and CHI Play from 2009 to 2019 often reference

BPNT, with approximately 84% discussing competency, 65% talking about autonomy and 57% considering relatedness [17]. SDT measurement instruments were used to obtain empirical results. The Intrinsic Motivation Inventory and the Basic Psychological Need Satisfaction and Frustration Scale (BPNSFS) are examples of questionnaires that measure one's perceived intrinsic motivation using Likert scales.

SDT is widely used in HCI, however, the theory is rarely utilized within the realm of haptic research. It is important to consider human motivation when creating novel technology in order to improve its acceptance. Research in SDT and open source software (OSS) communities reveal intrinsic motives such as the enjoyment of creating projects and learning new skills as drivers for OSS project participation [46, 47, 48]. OSS loyalty has also been found to be predicted from a user's initial interaction with the community, positing that deeper connections formed early on can influence positive intrinsic motivation [49]. Intrinsic motives such as supporting social exchanges within the community and acquiring new skills should be fostered in haptic platforms.

Self meaningfulness has also proven to be a foundation for intrinsic motivation and this can be applied through a mission statement. Wikipedia's mission statement provides clarity on what their users are ultimately striving for: greater shared knowledge with the intention to better the world [50]. A mission statement typically acts as a reminder of an organization's overall strategic and cultural objectives [51]. Mission fulfillment has been linked to stakeholder comprehension and commitment to the goals outlined in the mission statement. A collective understanding of the mission can also lead to quicker outcomes [52]. Mission statements are ubiquitous in the corporate world, but users of online communities may also reap its benefits.

The effects of verbal cues on motivation have revealed higher levels of basic need satisfaction when specifying intrinsic goals as opposed to extrinsic goals and when phrases are autonomy-supportive versus controlling [53, 54, 55]. To the author's knowledge, the effects of these motivators in the form of a mission statement have yet to be discovered within the haptics community.

Chapter 3

Designing the Haptiverse

The aim of this research is to support hapticians while they share their work with the global haptics community. A minimum viable product (MVP) of the Haptiverse is created based on existing literature of haptic collections. Additionally, design elements within the Haptiverse are evaluated using intrinsic motivation measurement tools and think-aloud observation tasks. We ask participants to complete anonymous surveys and a think-aloud task where they interact with the system to determine which design elements should be included in the final product.

3.1 Personas and Scenarios

Personas are descriptions of typical user groups, while scenarios detail how said users will interact with a product to achieve a specific goal. They are common practices in HCI and are powerful tools as they can help present ideas to stakeholders and determine product usability [56]. While personas and scenarios are ideally created after user studies, the Haptiverse is a novel product and the designers are simultaneously the stakeholders. Therefore, personas and scenarios were created prior to the studies in order to guide the initial design [57]. Scenarios and personas for both novice and expert hapticians can be found in the following sections.

3.1.1 Novice Haptician: Jenny

Scenario

AGE: 22 OCCUPATION: Fourth Year Systems Design Engineering Student at the University of Waterloo LOCATION: Waterloo, ON ARCHETYPE: The Novice	MOTIVATIONS: -Personal achievement -Acquiring new knowledge GOALS: -Build a simple haptic device for final course project -Taking a Haptics course in final term
 *"I find haptics quite interesting, however, I feel overwhelmed with where to start. Existing resources seem quite advanced and I am unsure if I have the skills to create my own haptic designs without a mentor."*	FRUSTRATIONS: -New to the field of haptics technology -Existing resources are too technical -Anxious about working with hardware and new software BIO: Jenny is a fourth year Systems Design Engineering student at the University of Waterloo. She has recently been introduced to the field of haptic technology through a Haptics course she is taking. She has never heard about haptics prior to the course but is fascinated by haptic devices such as Ultrahaptics. She hopes that the course will improve her technical skills as her confidence lacks in this area.

Figure 3.1: The Novice Haptician Persona

Jenny (22) is a fourth year Systems Design Engineering student who is currently taking a special topics course on haptics. The professor has asked that all students build a Haply device and create a single player game akin to air hockey. Jenny receives a disassembled Haply device and a piece of paper with a checklist of pieces that will be used to build the device. Due to the pandemic, the students are unable to build the device together. Therefore, having access to virtual tools, such as the Haptiverse, is more beneficial than ever before.

To begin, Jenny types, "Haply device" into the search bar to filter for haply device projects, referred to as Haptis within the Haptiverse. The collection returns a 3x3 grid of Hapti names and thumbnails. She notices a Hapti thumbnail that is highlighted. She reads, "Getting Started With A Haply Device" and immediately clicks on the Hapti. She follows the instructions on the Hapti's page, which redirects her to the GitHub repository for the Haply device. After following the GitHub repository, she successfully assembles the device and builds the Hello Wall game as part of the Getting Started instructions.

Jenny returns to the Haptiverse to browse other Haply games. She now enters the search

terms "Haply device games" and Haply games are subsequently returned on the same page. She sees a Leaf Toss game with a thumbnail of objects that could be transformed to a net and a puck. After reading through the description on the Hapti page, she decides to download the code files and change the images to resemble an air hockey game. She also realizes that the GitHub link is missing some instructions that she previously saw on the Hapti page. She refers to the instructions on the Hapti page in order to implement changes.

Once she has finished creating the air hockey game, she goes to the "Upload A Hapti" page to share her project with other hapticians. She fills out all necessary fields and clicks 'submit' on the page. She then goes back to the explore page, searches for her new Haply, and finds her Hapti's page.

3.1.2 Expert Haptician: Jay

<table>
<tr><td>AGE: 38
OCCUPATION: Co-Founder of Haply Robotics
LOCATION: Toronto, ON

ARCHETYPE: The Expert</td><td>MOTIVATIONS:
-Creating novel technology
-Advancing field
-Growing the global haptics community

GOALS:
-Improving products
-Share the Haply device
-Expand field of haptics</td></tr>
<tr><td> 
"I would like to share the Haply Development Kit with a larger audience so more people can learn about haptics."</td><td>FRUSTRATIONS:
-Contacting all stakeholders
-Finding resources to improve upon technology

BIO:
Jay is one of the founders of Haply Robotics. The first release of the Haply Development Kit was a success and the founders are working on the next version of the kit. The Haply force feedback device introduces novices to haptic technology. Jay is passionate about sharing the device and expanding the global haptics community.</td></tr>
</table>

Figure 3.2: The Expert Haptician Persona

Scenario

Jay (26) is one of the founders of Haply Robotics, a touch technology company that has created portable force-feedback devices. The company is about to release the second

version of its Haply device. They have updated their website and socials to announce the release of the new device, however, they know their customers do not frequently reference their website and need a way of reaching a wider audience. They have previously uploaded Haply content on the Haptiverse and are aware that many new customers often reference the 'Getting Started With A Haply Device' Hapti page within the Haptiverse. They decide that an easy solution to update their content is to simply update the page.

Jay logs into the Haptiverse and navigates to his Profile. From there, he can see the Haptis that he has previously uploaded to the Haptiverse on behalf of Haply Robotics. He wants to make sure the new device has its own Hapti page, so he goes to the Upload A Hapti page and uploads the information for a new Hapti. Once it is published, he searches for it in the Explore page.

3.2 The Haptiverse Sketches

Sketches of the Haptiverse were developed based on existing haptic and non-haptic online collections (Figure 3.3). Using the Thingiverse as inspiration, three pages were determined to be the focus when developing the first iteration of the Haptiverse:

Explore page. The Explore page will display either all the haptic content that has been uploaded to the Haptiverse or a specific subgroup. The Explore page's UI will use a symmetrical grid to display content, as it is a common UI design for online multimedia galleries. The objects in the Haptiverse, being the haptic content, are displayed on the Explore page through a thumbnail image and name to give users a preview of what the online collection contains.

Upload Content page. The Upload Content page is imperative to conducting this research; we need users to be able to upload haptic content to share with the global haptics community in order to grow the collection and have it be utilized. Existing research has confirmed the benefits of displaying a variety of examples in a collection [12]. Therefore, by encouraging hapticians to upload their work through a step-by-step process, we can expand the Haptiverse. The UI for the page will follow a multi-step form design. The initial sketch contains a single step form, but it was found to be quite daunting, as users are presented with a long list of fields they are required to fill in. Conversely, multi-step forms can show a subgroup of questions at one time which can avoid overburdening users. Reducing the number of questions on a form also allows for Gestalt's Principle of Proximity to be applied; more space on the form effectively spaces out and groups questions without overburdening the user with a long form. Additionally, Gestalt's Principle of Closure can

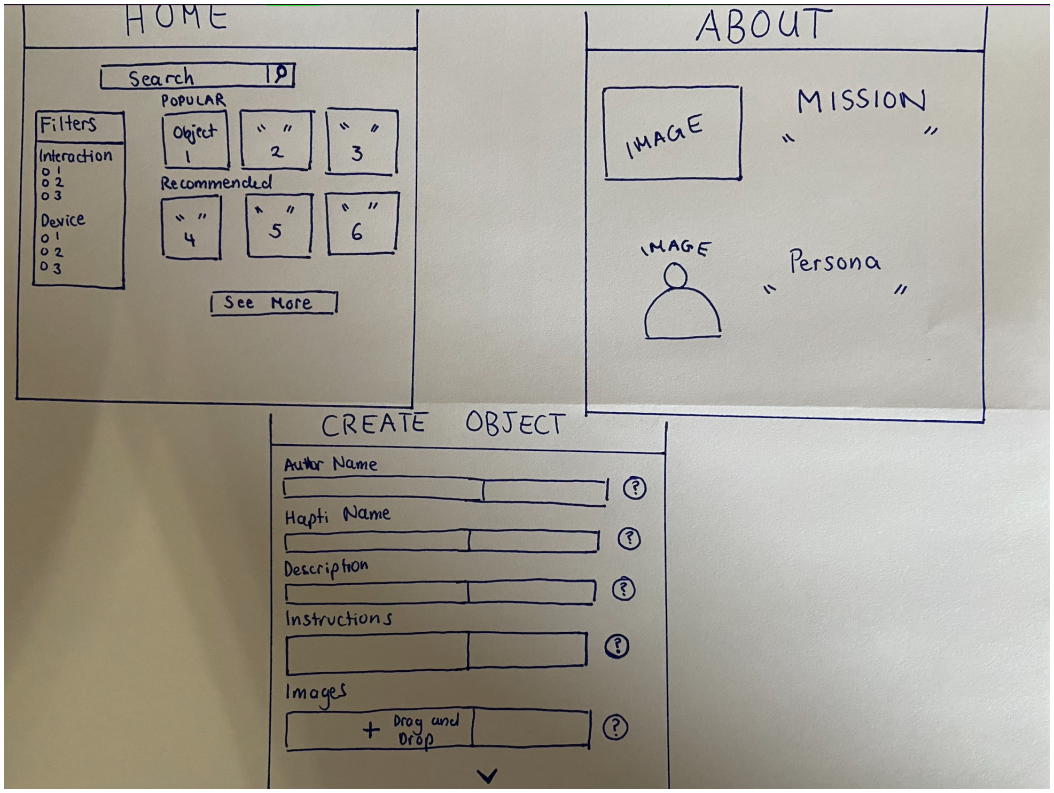

Figure 3.3: Initial sketches of the Home/Explore page, the About page, and the Upload Content Page

be applied to multi-step forms when a progress bar, or similar, is present. According to the principle, the human visual system prefers complete images, therefore it is important to strive to complete a visual. A progress bar that shows an incomplete task may encourage users to finish it in order to complete the progress bar [58, 59].

About page. The About page will feature a simple static form with the Haptiverse's mission statement. The mission statement is important as it identifies the overall goal of the Haptiverse and emphasizes the need to contribute to the collection. As a result, the text on the page is the priority as opposed to the UI design.

3.3 The Haptiverse Lexicon

To begin developing the Haptiverse, major concepts and vocabulary were created for the novel collection. By creating a lexicon for the system during the early stages of development, we can ensure consistency exists within both documentation and concepts visible to users from the system [60].

Hapti: Haptic content on the Haptiverse. For example, a VT icon or VT editing platform could be considered haptic content on the Haptiverse.
Hapti Types: A **Hapti** can either be a haptic experience, platform or supporting resource.
Haptic Experience: Haptic effects, interactions, and sensations (e.g. vibrotactile icons and force feedback effects).
Platforms: Software environments, libraries, and tools to create, modify, or run a haptic experience (e.g. Vibrotactile icon editor).
Supporting Resource: Tutorials on how to use a new device or platform (e.g. Getting Started Guide for using the Haply pantograph) or additional resources not covered.
Hapti Pages: Overview of **Hapti** content, with summary and tools to assist users getting familiar with the project. Should have associated files to recreate project.
Exploration: The type of search performed by the user. For example, this could be either text of the project name or using keywords to filter on effect and/or environment type to yield results of relevant **Hapti pages** (Results List).
Search Input: Input from the user (e.g. text, selections, etc.,) with the purpose of yielding a **Hapti** page.
Results list: A list of brief **Hapti** pages for the user to select from after entering **Search Input**.
Create Hapti: Upload haptic content to the Haptiverse to create a new **Hapti**.

3.4 Supporting the Basic Psychological Needs Theory

To support the three basic psychological needs: autonomy, relatedness and competence, in order to enhance users' intrinsic motivation to share their work using the Haptiverse, we will be incorporating two design features which we believe will positively influence users' basic psychological need satisfaction [16].

3.4.1 Design Feature 1: Mission Statement

Mission statements for online communities are seldom used in the field of haptics despite their use in not only OSS or open content production communities, but companies of all industries. Top Fortune 500 companies of 2021, such as Walmart, Mircosoft and Dell Technologies, have dedicated pages to describing what their company does and why it is relevant [61]. While some of these websites may not explicitly feature a mission statement, they often have an *About* or *Who We Are* section detailing the company's purpose and/or values.

Mission statements have been created for open content production online communities, such as Wikipedia, describing their goals and user expectations [50]. To the author's knowledge, the correlation between the linguistics of a mission statement and the perceived intrinsic motivation of users in a novel online community has yet to be evaluated. A study examining how specific intrinsic goals are presented in a mission statement and their influence on users may provide insight to novel OSS online communities looking to increase user adoption, as intrinsic motivations have been found to be drivers for continued participation [46, 47, 48].

We believe that a mission statement that identifies intrinsic goals as opposed to extrinsic goals will have a positive influence on users' basic psychological needs satisfaction. Intrinsic goals, such as community and learning new skills, can directly influence relatedness and autonomy which we believe will lead to adoption of the tool and build a sense of community. Therefore, we will create a mission statement for the Haptiverse with its goals being community and/or acquiring knowledge in order to target the two basic psychological needs, relatedness and autonomy.

Creating A Mission Statement

David et al. [62] identifies nine components of an effective mission statement from the customer perspective informed by strategic management researchers and practitioners. Seven of the nine components were used to create mission statements as two components were more corporate focused.

The seven components were slightly altered for the Haptiverse's online community. For example, the original components use the terms *customer* and *profitability*. To make the terms relevant to the haptics community, *customer* is altered to users and *profitability* refers to the adoption of the Haptiverse and growth of the ecosystem of haptic content. Descriptions of the components and how they will be satisfied with the Haptiverse are as follows:

1. **Users.** Who will the users of the Haptiverse be?
    - Users of the Haptiverse will be hapticians of all experience levels (e.g. novice, intermediate, expert, etc.).
2. **Product.** What is the Haptiverse?
    - The Haptiverse is a novel online collection for reuse of diverse haptic content.
3. **Market.** Where will the users of the Haptiverse be located geographically?
    - The Haptiverse is for the global haptic community.
4. **Technology.** This component questions how current the technology used will be.
    - The Haptiverse is a novel technology in itself.
5. **Concern for sustainability and growth.** How can the Haptiverse continue to grow and remain relevant?
    - The Haptiverse is designed to motivate its users to share their work with others. Through intentional design, we can influence the intrinsic motivation of users when interacting with the system.
6. **Philosophy.** What are the values of the Haptiverse?
    - The values of the Haptiverse are to acquire the sum of knowledge of all hapticians and share it with the greater haptic community, thereby inspiring innovative content that can connect users and better humanity.
7. **Competitive Advantage.** What sets the Haptiverse apart?
    - The Haptiverse will be the first platform hosting heterogeneous haptic content.

Three mission statements were created to satisfy the seven components, as indicated by their corresponding numbers from the list above. Varying intrinsic goals were used as the main focus of the mission statements [62].

Mission Statement 1
Intrinsic goal: Community

The Haptiverse's mission is to support hapticians share and ultimately reuse existing haptic content created by their peers through an online collection (2). Our goal is to

help strengthen connections within the global haptics community (1,3) in order to increase collaborations, thereby initiating the development of new and innovative haptic effects, interactions, software tools, and hardware designs (4,6) that can improve the overall well-being of humanity (5). We value the relationships within the community and believe a central platform designed for hapticians of varying experience levels will motivate them to learn and build upon each other's work (7).

Mission Statement 2
Intrinsic goal: Acquiring Knowledge

The Haptiverse's mission is to support both experienced and aspiring hapticians (1) to acquire new knowledge through an online collection of diverse haptic content (2). Our goal is to expand the known corpus of haptic content so that hapticians can acquire new skills and reuse existing haptic effects, interactions, software tools, and hardware designs (4,6). Through continued conversations with hapticians (7), we hope to better support their personal growth goals by gathering and sharing the sum of their knowledge (5) as they develop haptic solutions for the global haptics community (3).

Mission Statement 3
Intrinsic goal: Community & Acquiring Knowledge

The Haptiverse is committed to helping hapticians of varying experience levels (1) share their work efficiently with an online collection (2). Our goal is to facilitate the sharing of diverse haptic content (4) by helping hapticians to reuse existing knowledge and fostering new connections between said hapticians (5). Through continued assistance from the global haptics community (3), we can effectively create and maintain a tool which centralizes and shares the sum of work produced collaboratively by the haptics community (7). Subsequently, this can lead to the creation of haptic solutions that improve upon the overall wellbeing of humanity (6).

3.4.2 Design Feature 2: Upload Form

Existing repositories of haptic content are limited to a specific modality, such as VT icons or textures. To the author's knowledge, the Haptiverse will be the first online collection to host diverse haptic content. This content includes haptic effects, interactions, sensations, software tools, and hardware designs. Existing platforms, such as Haptipedia, use a Google form to request uploading new content [1]. We believe a multi-step upload form within the Haptiverse will guide users and simplify the upload process when trying to share content. In order to optimize the upload form, mandatory fields and groupings within the form must be identified.

Fields from Haptipedia, the 2diy Haply Robotics dev kit, and Thingiverse inspired the field selection for the Haptiverse. The online collections were chosen as they collectively provide a thorough list of fields for uploading diverse content and target both experts and non-experts. For example, the 2diy Haply Robotics dev kit gives clear step-by-step instructions so that novices can use the device. The sections used, such as "Assembling your device," inspired the hardware and software multimedia fields for the Haptiverse [6, 63]. Conversely, Haptipedia is an online taxonomy of haptic devices, therefore some fields may be too technical for novices but it is exhaustive for expert hapticians [1]. The following fields and their descriptions are described below.

Section 1: Author

1. **Author Name.** Full name(s) of haptic creator(s).
2. **Author URL.** Personal websites and social media links of the author(s).

Section 2: Haptic Info

1. **Hapti Name.** Name of project.
2. **Hapti Purpose.** Identify the purpose for creating the hapti. For example, the purpose of creating a game for the Haply device could be to show others how to create their own 2-DoF force feedback experiences.
3. **How does the hapti work?** The author is given a large free text field to explain the details of recreating their haptic project. Similar to what might be in a README.md file in a Github project.
4. **Hapti Type.** New field for the Haptiverse to categorize haptic content as either an experience, platform or supporting resource.

Section 3: Resources

1. **Image Thumbnail.** Image for the Explore page of the Haptiverse. Users are presented with a preview of each Hapti via a thumbnail image and Hapti name.
2. **Hardware Setup Multimedia.** Videos and/or images for setting up the haptic device.
3. **Hardware Setup Details.** A free text box is given to authors so that they can detail how to setup the hardware required for the project.

4. **Software Setup Multimedia.** Videos and/or images for setting up the software required to recreate the haptic project.

5. **Software Setup Details.** Another free text box for authors to detail how to setup the software involved in the project.

6. **Github Link.** Authors can share their Github link if hardware/software information is already detailed there.

7. **Copyright License.** The Haptiverse is an OSS community, therefore, a copyright license may be important to include in order to set the standards between the authors and anyone who wants to use their content [64].

Section 4: Tags

1. **Interaction Behaviours.** Authors can specify the haptic modality (e.g. VT icon, texture, and force feedback) of their project. This will be presented as a drop-down menu.

2. **Devices.** Authors can select the haptic device their project requires. This will be presented as a drop-down menu.

3. **Attribute Category.** Attribute tags that have been included in existing haptic repositories used to create the Haptiverse, such as VibViz, will be included in the attribute list [65]. For the first iteration, the hierarchy of attribute categories will be flat. This will be presented as a drop-down menu.

4. **Domain Skills.** In order to provide novices with transparency as to what skills are required to recreate the haptic project, we have created this field to specify any general skills, such as familiarity with a programming languages, needed for the project.

Section 5: Review & Submit
The final section of the multi-step form will present users with all the previous fields from the page and the answers they have entered. This will allow users to review their answers and subsequently make any modifications, if necessary.

3.5 Prototyping

Prototyping is an imperative step in the systems development life cycle. It helps designers to refine their ideas and perform user testing during the early stages of development [66]. Prototyping has allowed designers to measure the usefulness of a system, which has been correlated with future usage [67]. Neilsen identifies (1) horizontal prototypes, which present the overall system but limit functionality, and (2) vertical prototypes, which conversely present full functionality but provide a minimal view of the entire system. Both prototypes are useful as they limit the scope of the design while still having the capability to elicit feedback from potential users. Low to medium-fidelity prototypes, either vertical or horizontal, are not stand alone systems. However, these prototypes can be presented to target users in order to evaluate both the product's usability and user experience prior to the final product being created [68, 69].

A sample paper prototype of the Haptiverse was presented in Figure 3.3. The designs were iterated on and both medium-fidelity horizontal and vertical prototypes were created in Figma, an online prototyping tool. The Explore page and About Us page were presented as horizontal prototypes, as they were static pages. The Create Hapti page was made to be a vertical prototype as the process of uploading content to the Haptiverse was important to evaluate before creating a minimum viable product (MVP).

3.5.1 Figma Prototype

To create the Haptiverse Home page, external consistency with other public online collections such as YouTube, Pinterest, and Thingiverse was important to maintain. Thumbnail images and names were presented in a grid of 3-5 by N with the option to either like or save the content to the user's profile. We decided to label the Home page as the Explore page, as it more explicitly describes how the page should be utilized (Figure 3.4). The Explore page has also been incorporated in the Thingiverse, therefore, users of both platforms will find some external consistency.

The About Us page of the Haptiverse (Figure 3.5) presents users with an overarching mission statement. The mission itself is the main focus of the page, therefore, distractions such as large images and a vivid colour scheme were avoided to allow users to focus solely on the text as opposed to the aesthetics of the page. We also left a placeholder at the bottom of the page for a persona, which we intend to implement in the future; ideally users, particularly aspiring hapticians, can connect to the persona presented and ultimately understand how the platform can support their needs.

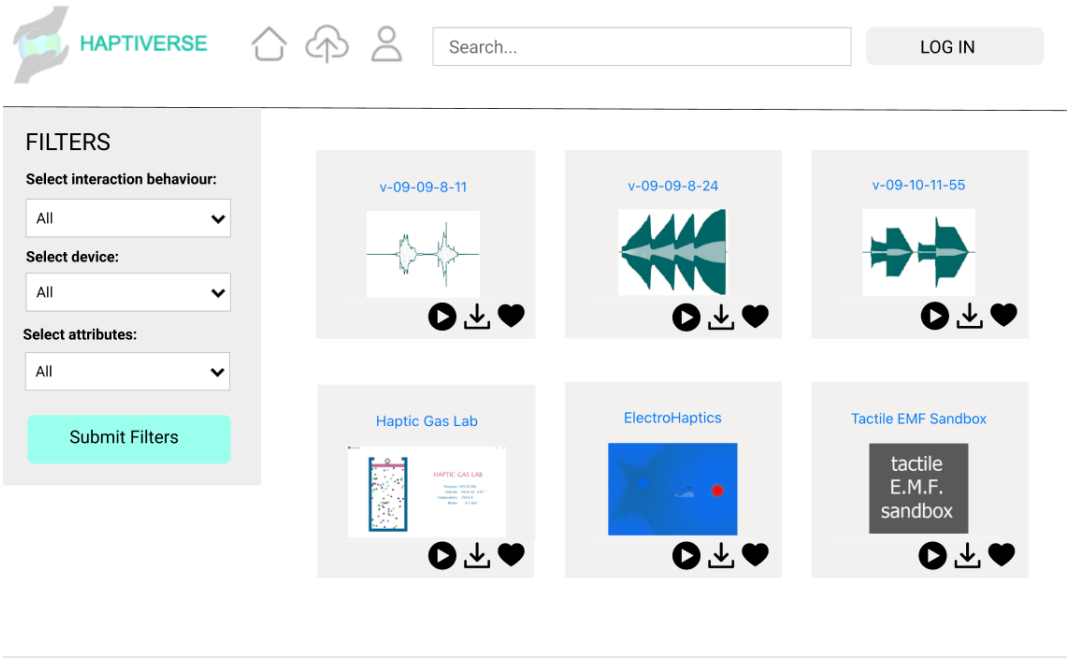

Figure 3.4: Explore Page

Upload Page: Iteration 1

The fields on the Upload page were initially presented in a single form to allow users to view them simultaneously (Figure 3.6). With limited fields in the initial paper prototype, we felt that a single page form would not overwhelm users. The "Upload a Thing!" page featured in the Thingiverse is also a single page form and is grouped by basic information and Thing details [29]. As we started to add more fields that we believed were necessary for novices to understand how to recreate a Hapti, we realized the single page form was too lengthy and needed to be organized into different sections.

Upload Page: Iteration 2

As more fields were added to the Upload page, it became increasingly challenging to implement Gestalt's Principle of Proximity and Closure as discussed in the Design chapter. Creating a multi-step form allowed us to reduce the fields displayed to users by grouping them based on authorship, high-level Hapti information, additional resources, and tags. By presenting users with each step at the top of the page, they can visualize their progress

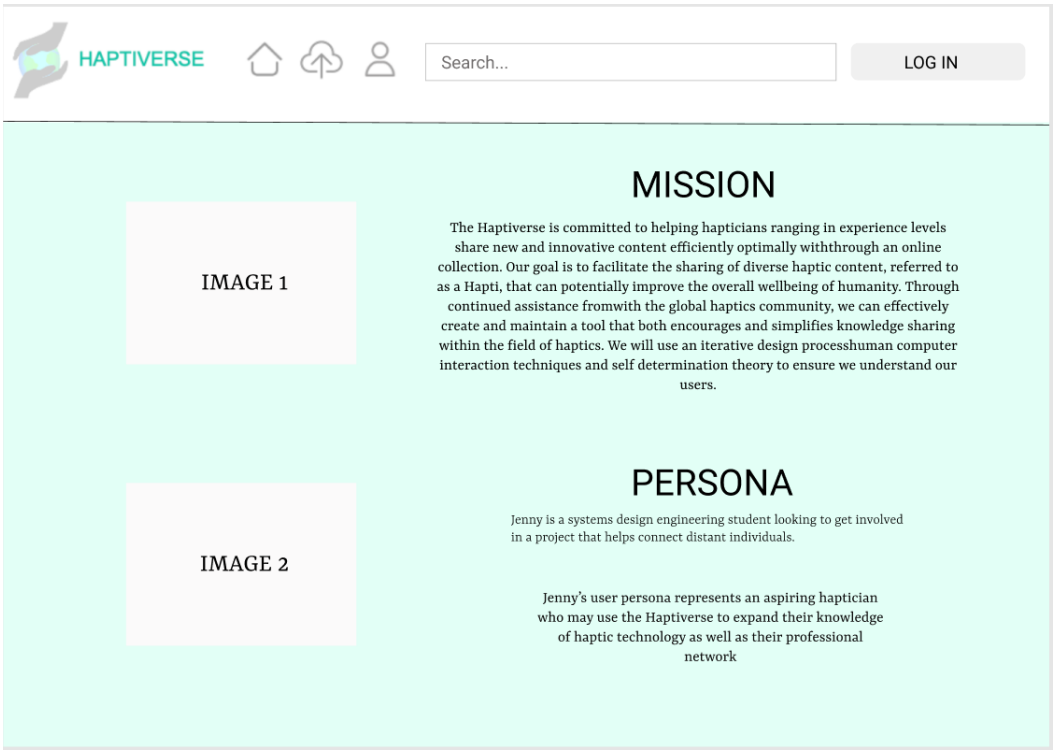

Figure 3.5: About Us Page

and navigate to previous steps if modifications are needed (Figures 3.7-3.11). We also decided to change the name of the Upload Page to the *Create Hapti* page in order for users to familiarize themselves with the Haptiverse term, Hapti.

3.5.2 High-Fidelity Prototype

Students from the Haptics Lab at the University of Waterloo developed a high-fidelity prototype of the Haptiverse by referencing the Figma medium-fidelity prototype. The high-fidelity prototype is important to create to evaluate the Create Hapti page. Due to being in the early stages of development, certain design features from the Figma designs are excluded. The differences are detailed below:

Create Hapti page is hidden. Due to the early stages of development, users will encounter issues when interacting with the high-fidelity prototype. For example, search is not exhaustive and Hapti pages may be incomplete. To avoid adding more content to the

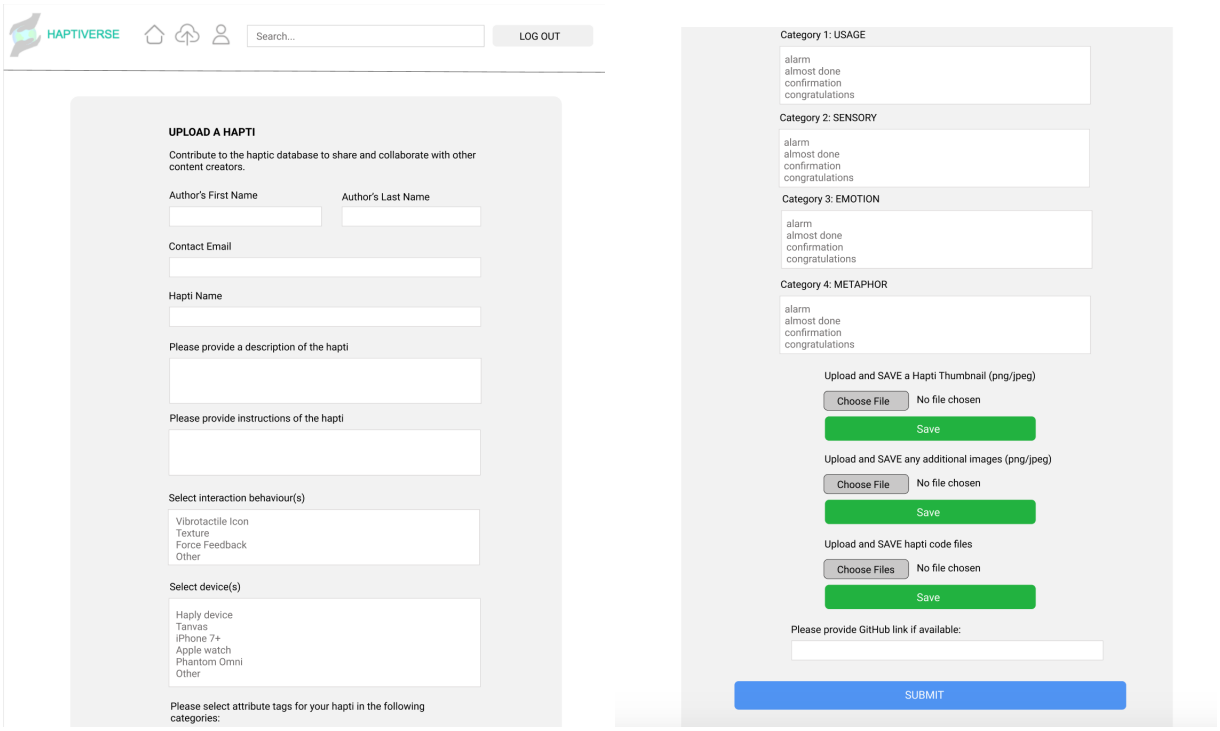

Figure 3.6: Upload Page

novel collection before it is user tested, we have chosen to hide the Create Hapti page so that it does not appear in the top navigation bar of the Haptiverse. This will ensure that only the users who are given credentials to login to the Haptiverse can upload content. Once users are logged in, there will be a "Create Hapti" option that appears under the user's profile.

Attributes are not categorized. The attribute list used for the Haptiverse is incomplete, as they are limited to the attributes from a few online repositories that were used to collect Haptis for the Haptiverse. The Haptiverse collection is still small in scale as we hope that it will receive a critical mass of users over time and that the collection of Haptis will grow exponentially. To keep the design simple and allow for future experiments involving the categorization of attribute tags, we did not implement a hierarchy of attributes. All attributes appear to be in the same group (Figure 3.12). We believe this may also spark conversation during experiments.

Drop-down menus are implemented. The Figma medium-fidelity prototypes initially display a few of the option for each field within the Tags section. For example, the

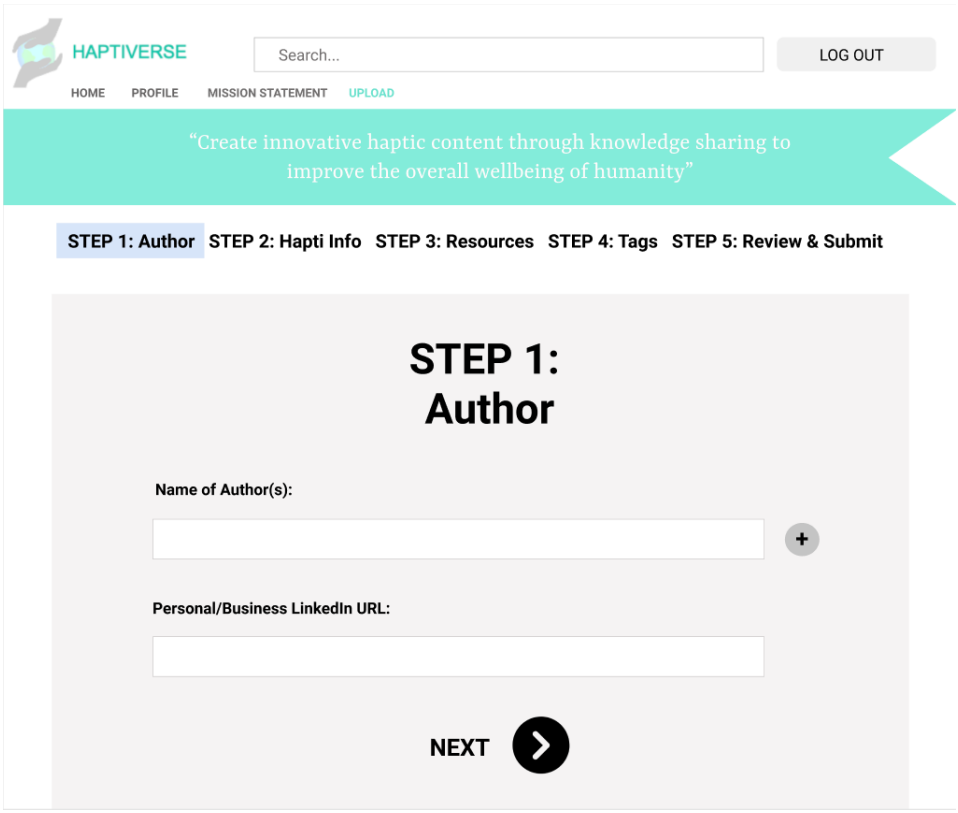

Figure 3.7: Create Hapti Page: Step 1

Device(s) field only showcases the Phantom Omni, Tanvas, Haply device, and other. We would like the most popular options to be displayed to users, however, this is still unknown as it requires deployment of the Haptiverse and tracking Hapti details. Therefore, drop-down menus that showcase all options for each field are implemented in the Tags section (Figure 3.13). To maintain internal consistency, the Hapti Type field within the Hapti Info section is also going to be a drop-down menu.

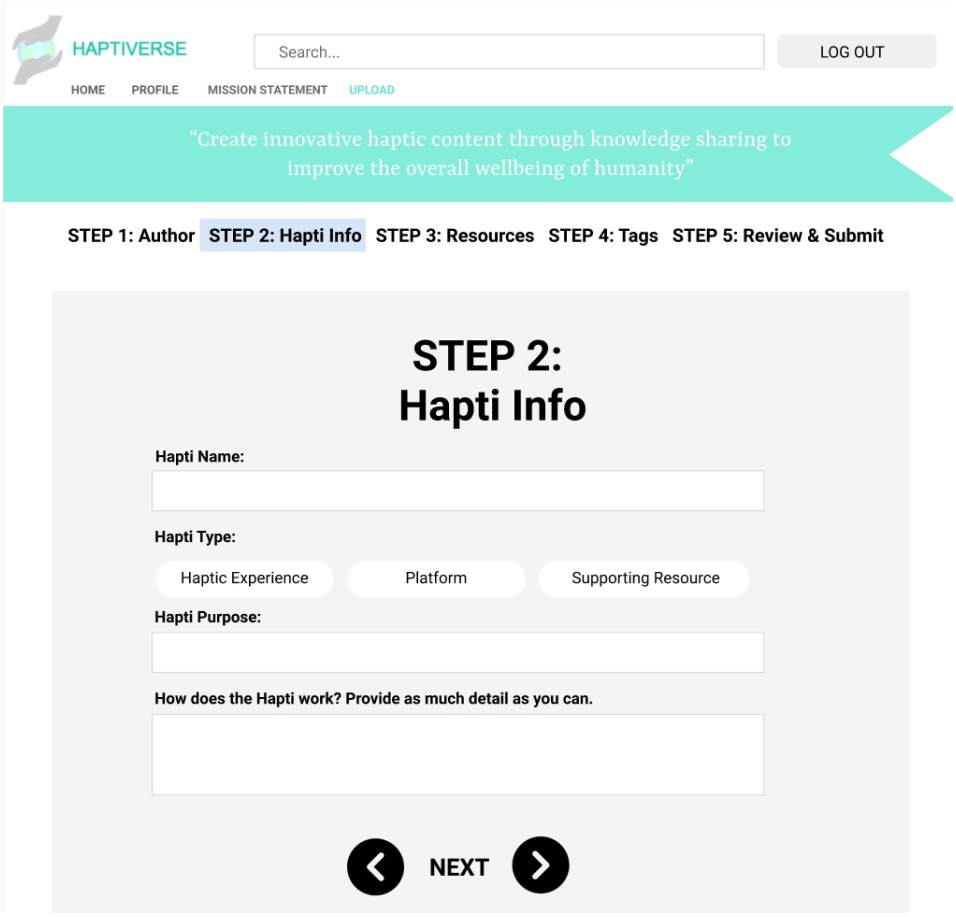

Figure 3.8: Create Hapti Page: Step 2

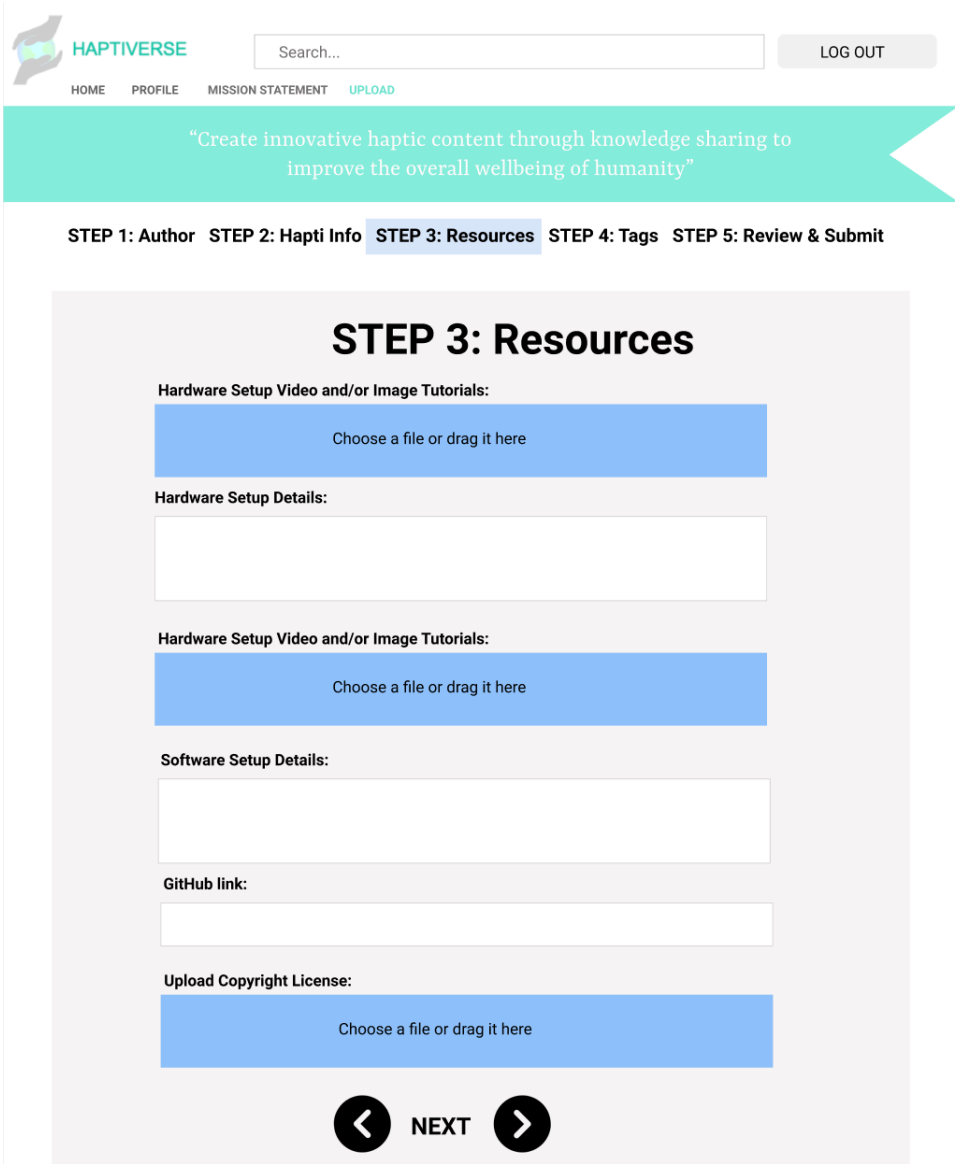

Figure 3.9: Create Hapti Page: Step 3

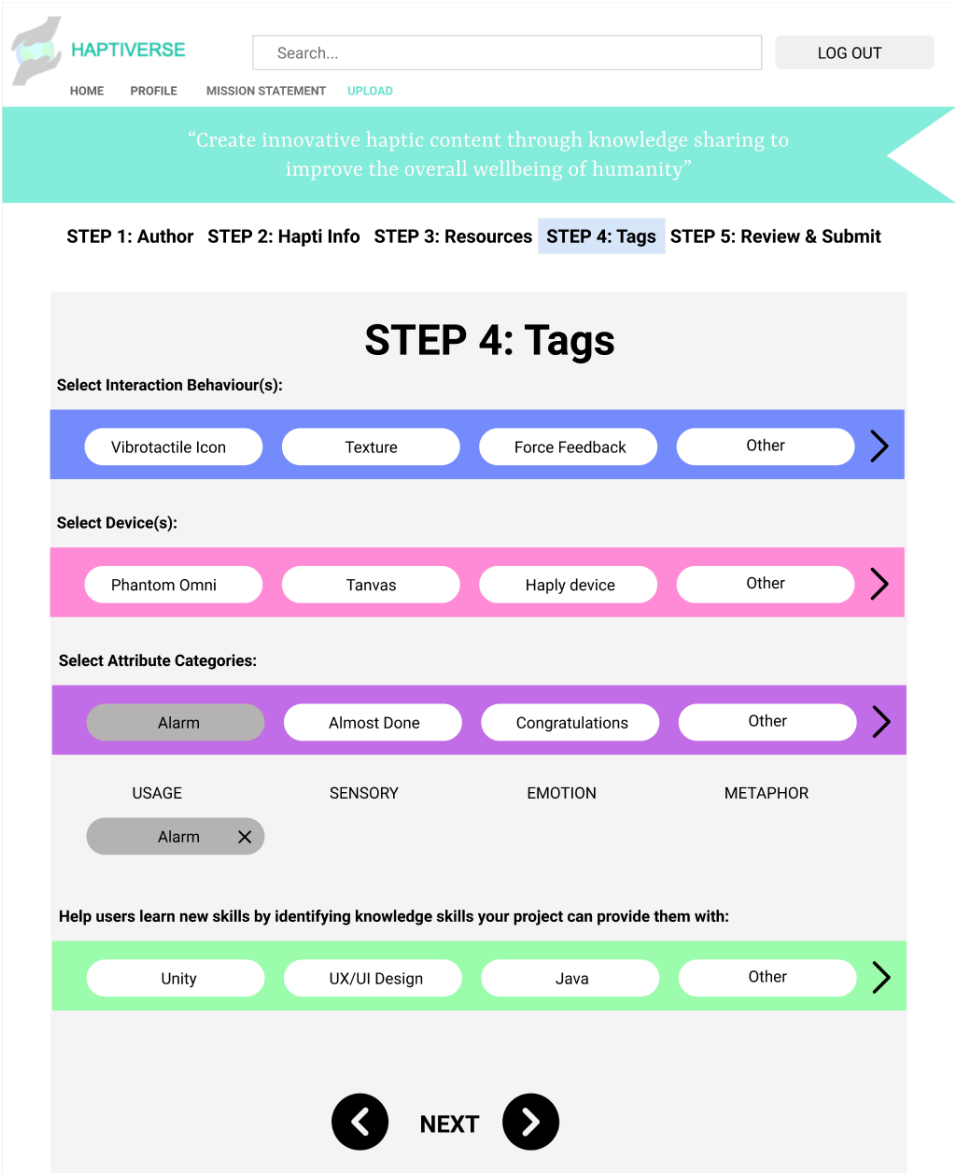

Figure 3.10: Create Hapti Page: Step 4

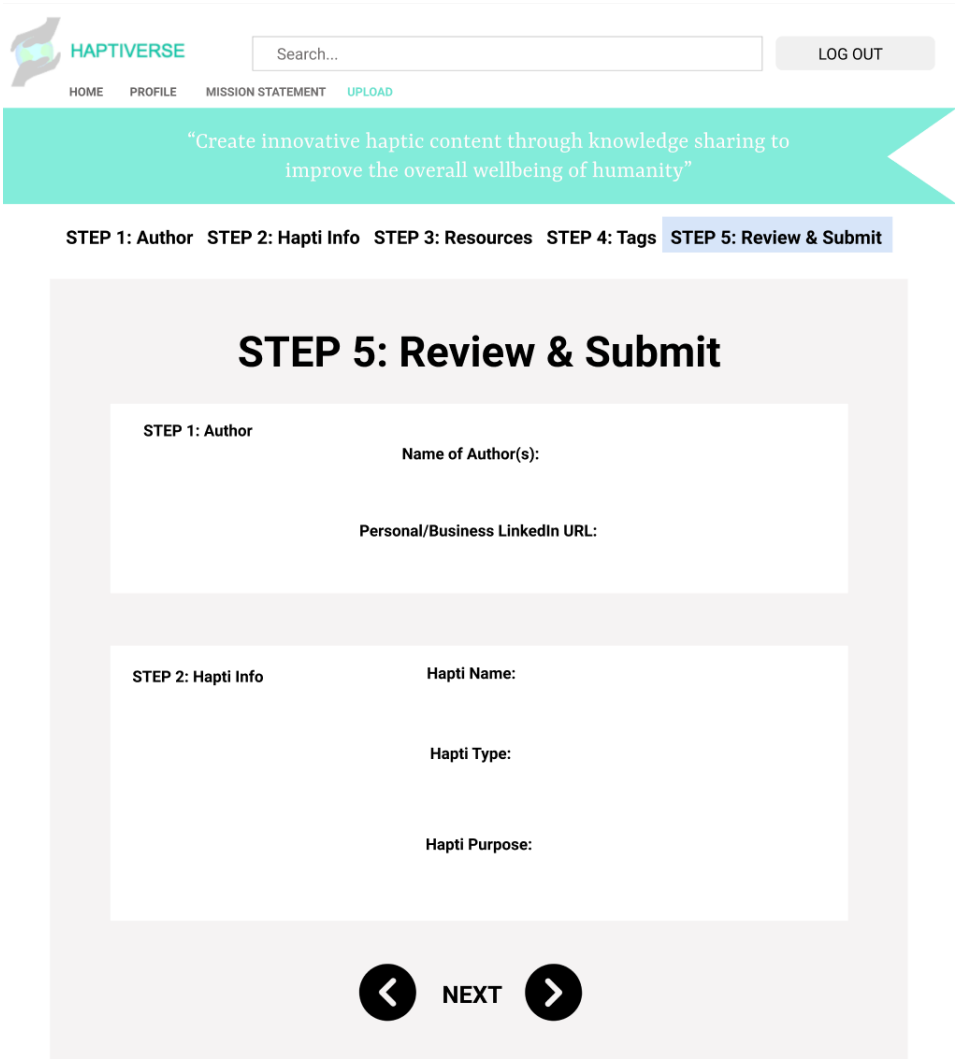

Figure 3.11: Create Hapti Page: Step 5

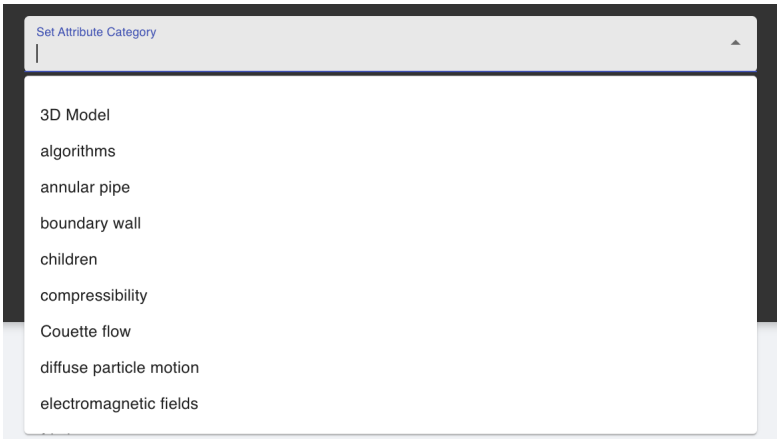

Figure 3.12: Attributes Drop-down

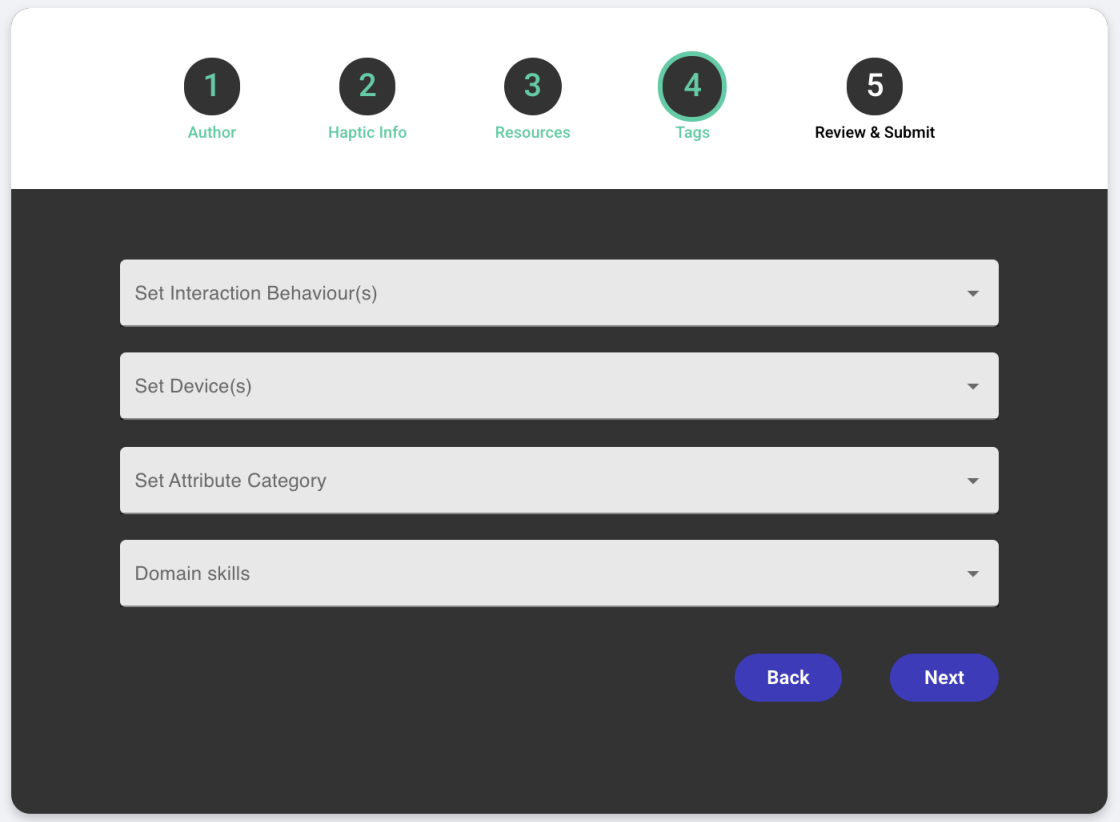

Figure 3.13: High-Fidelity Tags Section

Chapter 4

Experiment 1

The goal of the first experiment is to measure the basic psychological need satisfactions and frustrations of hapticians when reading the mission statements that have been crafted for the Haptiverse. Mission statements are both carefully created and valued in corporations, but to the author's knowledge, their impact on virtual haptics communities have yet to be evaluated [70, 51].

4.1 Description

An anonymous survey is used to evaluate three mission statements, each with varying intrinsic goals of focus. The results from the survey determine if a specific intrinsic goal has a greater influence on a basic psychological need over another and if it can ultimately internally motivate hapticians.

4.2 Participants and Apparatus

Participants were initially recruited online through professional and personal networks. Twenty-one participants submitted responses to the anonymous survey through Qualtrics, an online system for experience management. As outlined in the Self-Determination Theory Organization's Basic Psychological Need Satisfaction and Frustration Scale (BPNSFS), we implemented a Likert scale with one being synonymous with, "Not true at all," and five being synonymous with, "Completely true." Various versions of the BPNSFS scale

were provided, such as domain-specific questionnaires, however, we decided to use the English version of the general questionnaire for adults, as our participants are all English speaking and 18 years of age or older. The general scale consisted of 24 questions, with four questions directly measuring each basic psychological need satisfaction and frustration level. Favourable outcomes for the questionnaire are higher scores for satisfaction and lower for frustration. The original questionnaire and the reduced version have been validated by Chen and Vansteenkiste with culturally diverse samples [71].

The questionnaire was modified to measure the perceived need satisfaction and frustration of participants after reading a mission statement. Three variations of the Haptiverse's mission statement were provided to participants, as discussed in Design, and participants were subsequently asked to rank their perceived satisfaction and frustration after reading each mission. The mission statements were created to influence perceived autonomy and relatedness, so questions pertaining to competency were removed.

The statements provided in the questionnaire were altered to measure the influence of reading a mission statement as opposed to evaluating the entirety of the system. An example being the original statement, "I feel a sense of choice and freedom in the things I undertake." Participants may not directly connect this to the mission statement but may rank the statement based on their experience navigating the entirety of the Haptiverse. Alternatively, participants may not understand how to rank the statement at all. The statement was altered to, "I feel a sense of choice and freedom from reading the mission statement." Statements from the original questionnaire such as, "I feel that people who are important to me are cold and distant towards me," were also excluded from the questionnaire as they are irrelevant to reading a mission statement. The modified version of the questionnaire consisted of seven questions measuring perceived autonomy and five questions measuring perceived relatedness. The full list of questions can be found in Appendix A.1.

The order of the mission statements were the following: mission statement 1 (community), mission statement 2 (acquiring knowledge), and mission statement 3 (community and acquiring knowledge). The statements from the modified BPNSFS were randomized and presented after each mission statement.

4.3 Procedure

Beginner to expert hapticians were recruited through personal and professional networks via email and social platform groups to participate in the study. Anonymous survey links

provided by Qualtrics were distributed and a within-subjects experiment was conducted asking participants to complete the questionnaire online. Twenty-one complete answers were recorded within Qualtrics and the data was curated with Excel and analyzed with Python.

4.4 Results

Twenty-one participants between the ages of 18 and 54 completed the anonymous survey. Participants self-reported as 12 women, one non-binary, and eight men. Nine of the participants self-identified as either a beginner or novice haptician and 12 of the participants claimed greater familiarity with the technology, with some specifying that they were either an expert or intermediate. For simplicity, we have grouped beginner and novice hapticians under a single "novice" category, and all other participants as "experts".

Three mission statements were evaluated using the modified BPNSFS scale which consisted of a total of 12 questions for each mission statement. The statements were randomized through Qualtrics and participants were asked to rank each statement on a scale of one to five. To evaluate the results from each mission statement, the Python library, stats, was used. The Kruskal-Wallis test was used to analyze the data as it is a non-parametric test that does not assume the distribution of the data and can evaluate samples of varying sizes. By using the Kruskal-Wallis test, the null hypothesis when comparing groups is always such that the mean ranks are the same amongst the groups.

4.4.1 Haptic Experience

For the first evaluation, the nominal variable used for the Kruskal-Wallis test was *experience*, which classified participants as either novice or expert hapticians. The measurement variables were the scores for the following needs' satisfactions and frustrations: autonomy satisfaction (AS), relatedness satisfaction (RS), autonomy frustration (AF), and relatedness frustration (RF). The statements that were provided in the questionnaire could receive a possible score of one point to five points. The total maximum points for each measurement variable from each mission statement are the following: AS - 20 points, RS - 10 points, AF - 15 points, and RF - 15 points. Both AF and RF had a negative influence on the perceived need, therefore, lower scores were desired for these variables.

The results from the Kruskal-Wallis tests can be found in Table 4.1. The results from the test showed that all p-values were above 0.05, indicating no significant difference between

Table 4.1: Kruskal-Wallis Results by Mission Statement and Need Satisfaction/Frustration.

Mission	Need Satisfaction/Frustration	P-value
1	AS	1.0
	RS	0.2595
	AF	0.5893
	RF	0.9424
2	AS	0.7476
	RS	0.7469
	AF	0.1629
	RF	0.7666
3	AS	0.7732
	RS	0.1544
	AF	0.2249
	RF	0.5354

the novice and expert groups for each mission statement. Both expert and novice hapticians scored AS, RS, AF, and RF relatively similarly for each mission statement. The mean, median, and mode scores for each mission statement can be found in Table 4.2.

The Kruskal-Wallis test was also performed with the measurement variables remaining the same, but the mission statements being the nominal variable. The mission statements were assigned as either 1, 2, or 3 as the focus of each mission varied. Mission statement 1 was focused on community, mission statement 2 focused on acquiring knowledge, and mission statement 3 highlighted both community and acquiring knowledge. Details for each mission statement can be found in the Design section. Table 4.3 shows the results for each experience group and measurement variable.

The results in Table 4.3 revealed a significant p-value for the novice group when asked to rank RS. Therefore, we can reject the null hypothesis. In addition, pairwise comparisons

Table 4.2: Descriptive Statistics by Mission Statement.

Mission	Experience	Descriptive Statistic	Need Satisfaction/Frustration			
			AS	RS	AF	RF
1	Novice	Mean	14.56	6.89	4.78	5.22
	Expert		14.17	7.33	5.50	5.42
1	Novice	Median	14.0	7.0	4.0	6.0
	Expert		16.0	8.0	5.5	4.5
1	Novice	Mode	14.0	7.0	4.0	3.0
	Expert		12.0	8.0	3.0	4.0
2	Novice	Mean	15.11	6.77	6.22	4.33
	Expert		14.83	6.42	4.33	4.42
2	Novice	Median	15.0	7.0	5.0	4.0
	Expert		15.5	6.5	3.5	4.0
2	Novice	Mode	12.0	6.0	3.0	3.0
	Expert		16.0	9.0	3.0	3.0
3	Novice	Mean	15.56	8.11	4.22	4.33
	Expert		13.67	6.25	5.17	5.17
3	Novice	Median	16.0	9.0	4.0	4.0
	Expert		15.5	7.0	4.5	4.0
3	Novice	Mode	16.0	9.0	3.0	3.0
	Expert		17.0	3.0	3.0	4.0

Table 4.3: Kruskal-Wallis Results by Experience and Need Satisfaction/Frustration.

Experience Group	Need Satisfaction/Frustration	P-value
Novice	AS	0.6446
	RS	**0.0384**
	AF	0.2829
	RF	0.5171
Expert	AS	0.9828
	RS	0.5622
	AF	0.4200
	RF	0.5517

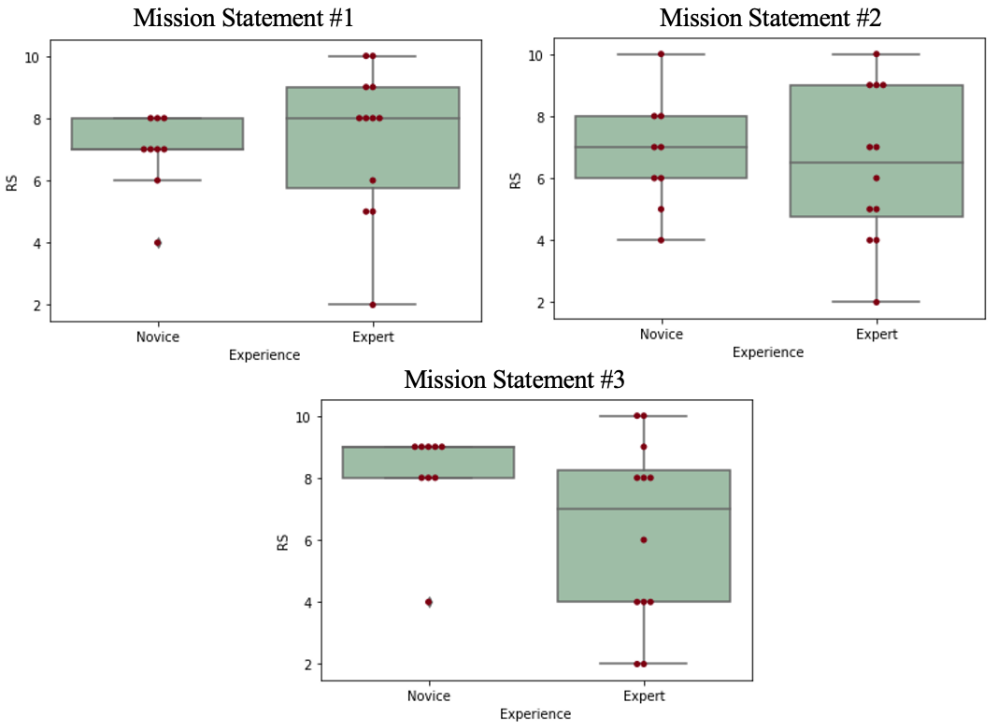

Figure 4.1: Relatedness satisfaction scores for the novice group.

were performed on the novices' data for each mission statement to determine which mission caused the difference in distribution. When pairing mission statements 1 and 2, a p-value of 0.7154 was returned, indicating no significance in distribution. Pairing mission statements 2 and 3 returned a p-value of 0.0578, and lastly pairing mission statements 1 and 3 returned a p-value of 0.0119. This is a good indication that the novices' data from mission statement 3 has a different distribution to that of mission statements 1 and 2. Mission statement 3 also has the most significant difference in distribution when compared to mission statement 1.

The relatedness satisfaction means are 6.89, 6.77, and 8.11 for missions 1, 2, and 3 respectively (Figure 4.1). The novice group scored RS higher for mission statement 1 in comparison to mission statement 2. This was expected given the first mission statement's focus on community, which directly correlates to relatedness. Mission statement 2 had a focus on autonomy, so its score for relatedness was expected to be the lowest of all the missions. Surprisingly, mission statement 3 scored significantly higher for RS in comparison to the other mission statements. The focus for mission statement 3 was both relatedness and

Table 4.4: One-way ANOVA by Need Satisfaction/Frustration.

Need Satisfaction/Frustration	P-value
AS	0.8619
RS	0.6821
AF	0.8007
RF	0.2711

autonomy as the haptics community and acquiring new knowledge were the stated goals. By combining intrinsic goals focused on both relatedness and autonomy, novices' perceived relatedness increased. The higher RS score occurred despite additional relatedness goals being introduced into the statement as the combination of autonomy and relatedness was influential.

4.4.2 Intrinsic Goals

The next evaluation eliminated experience and analyzed the scores against each of the three mission statements. The p-values across all mission statements for AS, RS, AF, and RF were 0.8627, 0.5371, 0.7148 and 0.3637 respectively. All p-values were above 0.05, therefore, we could not reject the null hypothesis.

One-way ANOVA tests were also performed on the data to identify any significance in the means of the groups of data as the distributions appeared to be similar, however, all p-values were above 0.05, indicating no significance (Table 4.4).

4.4.3 Qualitative Feedback

In addition to asking participants to rank mission statements using Likert scales, participants were given the option to provide feedback for each mission. A total of 12 participants chose to provide feedback and their responses have been summarized. The following question was asked to participants for all three mission statements:

How would you change Mission Statement <N>to make it more motivating?

Three common categories: motivation, community, and examples, emerged from the data and will be used to evaluate each mission statement.

Responses for Mission Statement 1

In terms of motivation, six participants did not explicitly state the influence the mission had on their motivation towards using the Haptiverse. One participant did not find the mission statement motivating as they wrote, "the mission statement was not entirely motivated as it did not address individuals who are new," revealing a need to possibly emphasize how the Haptiverse includes new hapticians. Conversely, five participants found the mission motivating as their feedback included words like, "inviting" and "welcoming."

For the second category, community, we analyzed whether the participants found the intrinsic goal to be the focus of the mission statement. Four responses were unknown, however, four participants communicated that community could be further emphasized. A participant wrote, "Perhaps an amendment could be to include further growing the community, raising awareness, and making the barriers to entering the community (such as knowledge gaps, lack of experience, etc.) as low as possible in the Haptiverse." Four participants found that community was well incorporated into the mission statement.

Lastly, examples were a common theme amongst the responses, as participants who expressed a need to emphasize community often did so by suggesting more examples. Five participants provided feedback about more examples as some wrote, "Potentially including more outcomes of the Haptiverse," and, "Understanding how it will help humanity." Four participants found the examples for the existing mission statement to be sufficient and three responses were unknown.

Responses for Mission Statement 2

Ten of the 12 participants provided feedback for Mission Statement 2. Seven participants found the mission statement to be motivating, as they expressed that they were very motivated or could relate to the mission. Participants also used the phrase, "more motivating," when providing feedback, insinuating there was already some influence on their motivation when reading the mission statements. The mean AS and RS scores for mission statement 2 were also above the neutral scores. Conversely, three participants did not state their motivations after reading the mission statement.

For the category, community, seven participants found that the mission statement did not highlight the intrinsic goal. An example of the need for including community is the following response from a participant, "This mission statement seemed less so about connecting hapticians to one another, but more so about connecting hapticians to the platform (i.e., the platform is offering support more so than the broader community). It would perhaps be more motivating to state that getting connected to the platform will create community among those who take part in it." Another participant also wrote, "The mission statement while motivational to novices, could have a broad inspirational statement

on the larger impact of such a community." These responses showcase a need to emphasize community in the Haptiverse's mission statement.

Of the 10 responses, six participants did not clearly state a need to provide more examples. One participant found that the mission statement was suffice as is, and three suggested more examples of how the Haptiverse might help its users. A novice haptician commented on the statement regarding continued conversations with the haptics community. Novices found the idea of *continued conversations* to be ambiguous and did not know what they would offer to the conversations since they are beginners.

Responses for Mission Statement 3

Eleven of the 12 participants provided feedback for the third mission statement. Six participants found the mission statement to be motivational, however, one participant found that it had the opposite effect. The participant found the mission statement to be difficult to read and found it to be too formal and superficial sounding. This contrasts the opinions of the other participants as they found that the missions statement captured the Haptiverse well and wanted even more examples. The four remaining participants did not provide feedback regarding the mission's motivational influence.

Most participants did not mention community for the third mission statement, however, two participants found that it incorporated community well and another two participants claimed it needed to be further emphasized.

The theme of examples was found amongst five participants, with statements such as, "Focus more on learning and reusing rather than just sharing," and, "A slight emphasis on learning will also speak to novices and be motivational," alluded to more examples for the intrinsic goal of acquiring new knowledge.

4.5 Discussion

The results from the anonymous survey revealed a significant p-value when comparing RS scores between all three mission statements for the novice group. This indicates that novices' perceived relatedness may be positively influenced by a mission statement that focuses on multiple intrinsic goals as opposed to a singular intrinsic goal. Although the first mission statement directly related to community, the third mission statement, which focused on both community and acquiring new knowledge, returned better RS scores. Conversely, there were no significant findings within the expert group.

When evaluating need satisfaction and frustration scores for all mission statements, regardless of experience level, no significant p-value was identified. This may indicate

that the mission statements are too similar as the authors for each mission statement were the same. Although a specific mission statement did not stand out when comparing need satisfaction and frustration scores, all mission statements had mean scores that were greater than the neutral scores, indicating a positive influence for participants' perceived autonomy and relatedness after reading the mission statements.

Our findings from the qualitative feedback indicate that the final mission statement for the Haptiverse could benefit from including more examples. Most participants wanted more examples of how the Haptiverse might help users as they were unsure of what the online collection was. Participants also expressed a need to further emphasize community. Having community be a focus of the mission statement may also increase and/or maintain novices' perceived competence, as the third mission statement revealed greater RS scores when community was identified as being one of the Haptiverse's goals.

Chapter 5

Experiment 2

5.1 Description

The goal of the second experiment is to determine if the Create Hapti multi-step form can influence users' perceived competence when interacting with it. Participants were asked to perform a think-aloud task in which they uploaded a haptic experience to the Haptiverse using the form. After the task, they were interviewed about the process and asked to complete an anonymous survey to measure their perceived competence.

5.2 Participants and Apparatus

Participants were recruited through professional and personal networks via email and social platform groups and nine people volunteered. Some of the participants for this experiment also participated in Experiment 1 as there is no overlap in apparatus.

The think-aloud tasks were completed virtually through the University of Waterloo's WebEx services, and the anonymous survey was done using Qualtrics. The anonymous survey used for this experiment was the Self-Determination Theory Organization's Perceived Competence Scale (PCS). Of the SDT measurements, it was reportedly one of the most face valid. The questionnaire consists of four items and are evaluated with a Likert-scale ranging from one point, being synonymous with, "Not true at all," to seven points, being synonymous with, "Very true." A higher score indicates a greater perceived competence experienced by the participant. Two versions of the questionnaire were provided, one for

diabetes and another for learning. The questionnaire for learning was slightly modified and used for this experiment (Appendix A.2) [71].

5.3 Procedure

Participants were asked to virtually complete a think-aloud task where they were instructed to talk out their thoughts and actions. They were also asked to share their computer screen with the researcher so that any patterns could be observed. The think-aloud task required participants to upload a haptic experience provided by the researcher through a Google drive folder to the Haptiverse. They were given the following instruction by the researcher, "Can you please go to the Create Hapti page and upload the haptic experience that I have sent in a google folder link in the WebEx chat?"

The task was designed to have participants find the Create Hapti page within the Haptiverse. In order to complete this task, participants had to login to the Haptiverse in order to access the page then complete all steps in the Create Hapti form. Once participants completed the task, they were asked questions regarding their likes and dislikes for the Create Hapti page and what they might change to optimize the process. Lastly, participants were asked to complete the PCS anonymous survey after the virtual meeting.

5.4 Results

Of the nine participants, five self-reported as women and four self-reported as men. Four of the participants self-reported as an intermediate or expert haptician, grouped under expert in this thesis, and the remaining participants self-reported as novices. All participants were between the ages of 18-44, with seven of them being between 24-34 years old.

5.4.1 Perceived Competency Scores

All nine participants submitted responses for the PCS questionnaire. The mean, median and mode have been calculated by experience level for each of the 4 items of the questionnaire (Table 5.1).

Table 5.1: PCS Descriptive Statistics by Experience.

Question	Experience	Mean	Median	Mode
1	Novice	6.2	6	6
	Expert	7	7	7
2	Novice	5.6	6	6
	Expert	5.5	5	6
3	Novice	5.6	6	6
	Expert	5	5	6
4	Novice	5	5	5
	Expert	6.25	6	6

The mean, median, and mode for all items of the PCS questionnaire, regardless of experience level, are above the neutral score of 4 from the Self-Determination Theory Organization's PCS measurement tool. The standard deviation for the entire group of data was 1.06, with question 1 having a standard deviation of 0.68, question 2 having a standard deviation of 1.16, question 3 having a standard deviation of 1.05, and question 4 having a standard deviation of 0.83. The standard deviation values indicate little variation amongst the data.

The high scores from the statistics in Table 5.1 are a strong indication that there is a positive influence on the perceived competence of users when interacting with the Create Hapti page. The statement, "I feel confident in my ability to learn the process to upload content onto the Haptiverse," most directly relates to the think-aloud task participants were asked to complete, while the remaining statements required participants to envision future outcomes of the Haptiverse based on their experience with the Create Hapti page. The statement most directly related to the think-aloud task received the highest mean scores of 6 for the novice group and 7 for the expert group. This is a strong indication that the participants felt comfortable uploading content to the Haptiverse through the Create Hapti page. The lowest mean scores of 5.6 for the novice group and 5 for the expert group were given to the statement, "I am able to achieve my goals with the Haptiverse." This outcome was expected as there are many use cases for the Haptiverse, and participants were unable to interact with the entirety of the system in its final version. Therefore, participants could only predict what they would use the Haptiverse for given their experience with the Create Hapti page and knowing the purpose of the system.

5.4.2 Qualitative Feedback

We have summarized our findings from the thematic analysis of our interviews with two main questions.

Q1. What were your likes and dislikes with the Create Hapti page?
The most common response from participants was that the Create Hapti page was, "straightforward" and that they liked the top bar navigation for each section of the multi-step form. Participants' interactions with the multi-step page as they completed the think-aloud task followed this response as there was little hesitation when filling in the fields. However, fields that were novel to novices, such as interaction behaviours and attributes, revealed hesitancy. A field that we noticed many users struggling with, especially novices, was the Hapti type field. Descriptions for each Hapti type (experience, platform, or supporting resource) were only visible upon selection. Users would click the drop-down menu for the field and be confused as to which type to select. They were unaware of the descriptions as they didn't choose to select an option. The attribute field also brought about conversation as the attributes presented via a drop-down menu had no obvious categories, so users were confused as to why general attributes, such as game, were in the same level as an attribute such as buoyancy. A participant suggested, "wind force and buoyancy could be under fluids or fluid mechanics," and multiple participants mentioned adding in new attributes, as this was not a feature yet implemented. An expert participant also suggested separating the attribute field into two categories, one to describe the haptic experience itself and another for more general attributes. Overall, we found that participants found the process to be straightforward, however, technical fields may benefit from examples and/or descriptions in order for beginner hapticians to have a better understanding of what they entail.

An unforeseen issue that we did not anticipate was the location of the Create Hapti page within the Haptiverse. Participants were given a link to the Haptiverse's default navigation page and asked to go to the Create Hapti page. The page itself was only visible to users after they logged in to reduce illegitimate Hapti uploads. All participants struggled to navigate to the Create Hapti page and vocalized their confusion.

Q2. What might you change to optimize the current process of uploading new haptic content or do you believe the Create Hapti page is optimal?
All participants found the Create Hapti page to be quite clear and many expressed that the process seemed optimal. Participants found that certain fields could be modified in order to make them clearer to users, but found the overall process and separation of sections to be straightforward. Some participants suggested providing users with an introduction to what the Create hapti page was or giving users an example of an existing Hapti with fields filled in for each.

5.5 Discussion

Overall, the results from Experiment 2 were positive as the mean scores for each statement of the PCS were greater than the neutral score, and the feedback from the interview portion of the study indicated that the process was straightforward for both the novice and expert groups. Most participants found the process of uploading content to the Haptiverse to be optimal and all participants successfully completed the think-aloud task of going through the Create Hapti page to upload a haptic experience.

Participants' suggestions, such as including visible descriptions for more technical fields, gave good insight as to how the form could have a greater influence on users' perceived competence. The location of the page also seemed sub-optimal and it would make more sense to have the page appear in the top navigation bar of the Haptiverse regardless if users are logged into the system. In addition, a participant commented that there was room for expansion with the Haptiverse, such as being able to track and report on current trends. For example, the Create Hapti form can display the most popular attributes so that users can see what kind of content is trending. A participant also added including a use case field to identify who the content is created for, as this may be imperative information for researchers.

Chapter 6

Conclusion

6.1 Design Implications

The results from Experiment 1 and Experiment 2 revealed design features that may impact a user's perceived autonomy, relatedness, and competence. Hapticians seeking to create a variation of the Haptiverse can reference the design implications outlined below.

Incorporate community when creating a mission statement. All three mission statements from Experiment 1 resulted in favourable average perceived autonomy and relatedness scores. However, the novices group experienced greater levels of perceived relatedness after reading a mission statement that incorporated both community and acquiring new knowledge as its intrinsic goals. Participants also provided feedback via a text box, which suggested a greater emphasis on community, especially for those new to haptics. Novice hapticians may not have any initial motivation to use the Haptiverse as they are much less likely to have experienced any enjoyment-based intrinsic motivation working with haptic content, in comparison to expert hapticians [46]. By incorporating more of a community focus into the Haptiverse's mission statement, novice hapticians may feel more welcomed into the novel online community and inspired to discover more about haptic technology using the collection.

A multi-step form can optimize the uploading of work to an online collection. Participants from Experiment 2 vocalized that they felt the multi-step Create Hapti form was straightforward, and that the compartmentalized structure of the form was helpful. Participants were also asked if they thought the process of uploading content to the Haptiverse was optimal, and most participants vocalized that they believed that it was.

Technical fields need descriptions. Most of the fields from the Create Hapti form were clear to participants. However, technical fields, specifically Hapti type, attributes, interaction behaviours and devices, were not as straightforward to beginner hapticians. During the think-aloud task in Experiment 2, novice hapticians spent the majority of their time on the Hapti type and attributes fields. Given the novelty of the Hapti type field, a description and/or example might help to provide users with more clarity. The attributes field was also found to be confusing to novices and even some expert hapticians, as they were unsure of what designated a specific word as an attribute. The attributes presented to users did not have a hierarchical structure and/or clear category. Participants suggested categorizing the attributes into common themes; an expert recommended separating general descriptors about the haptic project and adjectives about the haptic experience itself into two distinct attribute categories. The interaction behaviours and devices categories are necessary to specify when trying to recreate haptic content. Interaction behaviours and haptic devices, however, are not common knowledge to novices, therefore providing examples for each would be beneficial for users.

Provide examples when introducing a new process. The Create Hapti form is a novel process for the haptics community. To the author's knowledge, a multi-step form for uploading diverse haptic content has yet to be introduced. While the Create Hapti form had self-explanatory fields, such as author and Hapti name, participants experienced some hesitancy when interacting with the novel process. In Experiment 2, novice hapticians seemed confused when introduced to the Create Hapti page as they were unsure of the purpose of the page until they began to interact with it. Multiple participants were confused as to what a Hapti is, as this is a new term that was created specifically for the Haptiverse. Participants suggested providing an example Hapti, with the fields from the Create Hapti form already filled in. An introductory step detailing what the Create Hapti page entails was also proposed, as the name and process were not intuitive to all participants. By incorporating an example Hapti and brief introductory page, users of the Haptiverse may better understand the process, namely non-experts who often prefer concise and direct content [72].

Ensure users are able to easily navigate to necessary pages. While this may seem trivial, the Create Hapti page was only visible to users once they were logged into the Haptiverse, in order to minimize inappropriate uploads. The main purpose of the Haptiverse is to allow hapticians to easily share their work with the haptics community. Therefore, the Create Hapti form is an imperative part of the Haptiverse and should not be initially hidden to users. To avoid inappropriate uploads, perhaps administrators of the Haptiverse can review and verify all uploads after a certain amount of days from when the Hapti has been uploaded to the system.

6.2 Conclusions

This thesis presents the Haptiverse, an online collection for the reuse of diverse haptic content. The collection was designed to positively influence users' basic psychological needs of autonomy, relatedness and competence, in hopes that it would internally motivate hapticians to share their work with the entire haptics community via the novel system. We believe that designing a system that targets each basic psychological need can increase the usability of the system and encourage its widespread adoption.

6.2.1 Limitations

The limitations of the results from this thesis are outlined below.

A positive influence in autonomy, relatedness, and competence while using the Haptiverse does not ensure prolonged internal motivation. While the combination of the mission statements and Create Hapti form had positive results in participants' perceived basic psychological needs, there is no evidence that it correlates to sustained internal motivation when interacting with the Haptiverse, as the system is still under development. We assume users' internal motivation is supported based on the positive influence on participants' perceived basic psychological needs. To determine its influence on continued usage of the system, a long term study evaluating users' motivations when interacting with the system would be beneficial.

The results for the mission statements do not extend to all autonomy and relatedness focused intrinsic goals. The results from Experiment 1 indicated a positive influence on the perceived autonomy and relatedness of participants when targeting these basic psychological needs through the highlighting of two goals: community and acquiring new knowledge. Nevertheless, this does not extend to all intrinsic goals that relate to autonomy and relatedness. For example, the intrinsic goal of meeting expert hapticians can be connected to relatedness, however, this is not analogous to the Haptiverse's goal of sharing work with the haptics community and making connections with both aspiring and expert hapticians. Therefore, more granular intrinsic goals should be evaluated in order to ensure their influence on a user's basic psychological needs.

Small sample sizes for experiments. Both Experiment 1 and Experiment 2 had relatively small sample sizes, 21 and nine respectively. A greater number of participants varying in both age and geographical location would provide more insight into how the Haptiverse can truly support the global haptics community.

The BPNSFS has not been validated for mission statements. The original BPNSFS has been validated, however, the modified version used in Experiment 1 has not been validated when used for mission statements.

The PCS results may not reflect users' perceived competence towards the fields within the Create Hapti form. While the intention of Experiment 2 was to use the modified PCS to measure the perceived competence of participants when interacting with the fields within the Create Hapti page, the measures may reflect their perceived competence towards filling out a general form. Participants may fill out forms frequently, therefore their perceived competence could be higher due to their familiarity with the layout of the Create Hapti page as opposed to finding familiarity with the terms presented in the multi-step form. In addition, measures of usability have not been separated from the PCS scores, therefore, the ease of use of the page may strongly contribute to the higher scores as opposed to participants' abilities to provide Hapti details for each section of the form.

6.2.2 Future Work

Future design recommendations and continued research directions for the Haptiverse are detailed below.

Have different authors create mission statements and iterate. Experiment 1 consisted of three different mission statements all written by the same authors. The results from the experiment indicated that the influence of these statements on users' perceived autonomy and relatedness were similar and no significant differences were observed, with the exception of the relatedness scores of the novice group for the third mission statement. The similar perceived autonomy and relatedness results are likely due to the identical authorship of the mission statements. The mission statements consisted of similar phrasing and synonyms, which may have resulted in the participants being unable to identify a major difference between them. Regardless of the fact that the intrinsic goals of each mission statement differ, the common structuring of the mission statements likely resulted in similar perceived autonomy and relatedness scores. Multiple iterations of the mission statements would also be helpful to ensure the scores of participants are maximized.

Include an example Hapti and an introductory page to the Create Hapti form. Participants from Experiment 2 provided feedback on the Create Hapti form, which included having descriptions for each field and/or an example Hapti available on the form. We propose that a future experiment for the Haptiverse should implore new participants to go through the Create Hapti page, but with an introductory page and an example Hapti included within the form. For example, a brief description of the Create Hapti page can

be implemented as the default page once clicking into the Create Hapti form. The introductory page can also include an example Hapti, such as a Haply device game, which will illustrate that the fields in the proceeding sections of the form will feature focused placeholders so that users can better understand how to fill everything in.

Track and report on Hapti details to present current trends in the data. A participant from Experiment 2 suggested that there exists room for expansion of the Haptiverse after they interacted with the Create Hapti form. They stated that fields such as attributes could be reported on and visible to future users of the Haptiverse. Extending this to devices and interactions could further inform users what kinds of haptic content are trending. For example, if users were able to see the most popular haptic devices used for Haptis, they can then create haptic experiences compatible with the device, which may increase its exposure on the Haptiverse.

The results from this thesis showcase the potential that a mission statement and multi-step upload form possess to positively influence users' basic psychological needs when interacting with a novel online collection of diverse haptic content. Through future experiments and iterations of the Haptiverse, we believe the collection can influence users' basic psychological needs in an increasingly positive manner, in turn internally motivating users to share their work using the Haptiverse.

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APPENDICES

Appendix A

Anonymous Survey Questionnaires

A.1 Modified BPNSFS Questionnaire

Autonomy Focused Statements

1. I feel a sense of choice and freedom from reading the mission statement.
2. Most of the goals expressed in the mission statement makes me feel like "I have to" align with them.
3. I feel that the goals in the mission statement reflect what I really want.
4. I feel forced to do many things I wouldn't choose to do using the Haptiverse.
5. I feel the mission statement expresses who I really am in the haptics community.
6. I feel pressured to do too many things expressed in the mission statement.
7. I feel like I can do what really interests me using the Haptiverse.

Relatedness Focused Statements

1. I feel excluded from the Haptiverse's virtual community.
2. I feel a sense of closeness and connectedness with other people in the Haptiverse's virtual community after reading the mission statement.

3. I have the impression that the members of the Haptiverse's virtual community will dislike me.

4. I feel the relationships in the Haptiverse's virtual community are just superficial.

5. I experience a warm feeling with the Haptiverse's virtual community after reading the mission statement.

A.2 Modified PCS Questionnaire

1. I feel confident in my ability to learn the process to upload content onto the Haptiverse.

2. I am capable of learning material that has been uploaded with the 'Create Hapti' form within the Haptiverse.

3. I am able to achieve my goals with the Haptiverse.

4. I feel able to meet the challenge of creating and sharing novel haptic experiences using the Haptiverse.