AnatoView: Using interactive 3D visualizations with augmented reality support for laypersons’ medical education in informed consent processes

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AnatoView: Using interactive 3D visualizations with augmented reality support for laypersons’ medical education in informed consent processes

A Thesis
Submitted to the Faculty
in partial fulfillment of the requirements for the degree of

Master of Science
in
Computer Science
by Michelle Chen

Guarini School of Graduate and Advanced Studies
Dartmouth College
Hanover, New Hampshire
August 2023

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Abstract

Problem: Informed consent (IC) requires patients to adequately comprehend medical procedures before consenting to receive them. Medical literature, however, has found that the traditional IC process, in which a healthcare provider explains the procedure, leads to poor comprehension — a major inadequacy that compromises patients’ healthcare and safety.

Objective: To assess the efficacy of an interactive multimedia educational application AnatoView, which visualizes medical procedures in three-dimensional (3D), augmented reality (AR) space, on improving laypersons’ comprehension of procedures during IC.

Design: A mixed study conducted through a randomized, controlled trial with 15 laypersons as participants.

Interventions: For the control group (non-users), a traditional IC process between an individual participant and a physician. For experimental groups (users), an IC process between participant and physician, supplemented by the use of AnatoView. One user group (Group C) had access to an AR-supported viewport, whereas the other (Group B) used a strictly 3D viewport.

Main outcome measures: As a primary outcome, medical comprehension was measured through the change in participants’ scores on a 10-question comprehension assessment given pre-and-post-intervention. As secondary outcomes, communicativity was measured through the number of questions participants asked their physician, and engagement was measured through the percentage of participants who report feeling engaged while learning.

Results: Users demonstrated significant improvement vs. non-users in all three major outcomes of medical comprehension (4.3 vs. 2.8; p = 0.04), communicativity (4.4 vs 0.4; p = 0.01), and self-reported engagement (100% vs 40%; p = 0.02). Within
Group C, self-reported familiarity with AR was a predictor for improved comprehension ($R = 0.67$, $\beta = 0.79$).

**Conclusions:** *AnatoView* was a highly effective learning supplement for laypersons’ medical comprehension: it equipped users with the visuospatial cognition necessary for their medical comprehension; facilitated non-verbal communication that was visual, tactile, and accessible for laypersons; helped users play an active role in their learning; and allowed users to learn at their own pace. The benefit of *AnatoView*’s AR features was highly dependent on users’ familiarity with AR — reifying the importance of tailoring IC interventions to individual needs for optimal learning outcomes.
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1 Introduction

1.1 Informed consent

1.1.1 Definition

Informed consent is a mandatory prerequisite to medical intervention that requires patients to adequately comprehend a proposed procedure before consenting to receive it. This process traditionally consists of a face-to-face conversation between a patient and healthcare provider, wherein the provider delivers a spoken explanation of the proposed procedure, as well as its associated risks, benefits, and alternatives, before soliciting the patient’s consent — whether the patient accepts or refuses the treatment — via a signature on a printed form. During the process, patients are able to ask questions about the procedure.

1.1.2 Significance

Informed consent is a preeminent patient safety protocol that is critical to effectively providing high-quality and patient-centered healthcare. The failure to adequately ensure informed consent compromises the autonomy of a patient [1][2], endangers their safety [3][4][5], and may legally constitute negligence or battery if wrongly executed [1][6].

1.1.3 Current shortcomings

Despite the interwoven practical, ethical, and legal significance of informed consent, there are several shortcomings to current and conventional implementations of the process. Chief among these shortcomings is an inadequacy in actually informing patients of the proposed medical intervention. Medical literature describes current
communication methods as “often limited,” “highly variable,” and prone to “leav[ing] the patient unsatisfied with the amount of information received” [7][8][9][10][11][12], such that patient comprehension is often poor as a result [13][7]. According to several public health organizations and studies, specific shortcomings that warrant inspection, reform, or improvement, include

- The use of a patient’s signature on a consent form as an indication of their understanding [14];
- The use of complex language on consent forms, i.e. jargon or other verbiage above many patients’ reading levels, that is difficult for patients to understand [15][16];
- Limitations to spoken communication between patients and providers: providers will typically use spoken English to convey information to patients, such that patients who have limited or no English literacy and/or non-auditory learning needs are unaccommodated and left at increased risk for poor comprehension [17][18].

Several organizations, such as the Agency for Healthcare Research and Quality (AHRQ), the National Quality Forum, and the American Medical Association have concurred with these assessments and called for improvements to the informed consent process [4].

1.2 Proposed solution to improving informed consent

To address these shortcomings in the traditional informed consent process, we propose AnatoView: an interactive multimedia educational application that combines informative text and three-dimensional (3D) visuals to teach its primary audience of laypersons about medical procedures. AnatoView’s educational modules are delivered in a ‘walkthrough’ format, where procedures are broken down into discrete,
sequential, step-by-step explanations tailored to a layperson’s background and level of understanding. Users are able to navigate between steps in the walkthrough, progressing forward and backward at their discretion so as to learn at their own pace. Additionally, *AnatoView*’s 3D visualizations of procedures are displayed in an interactive viewport that invites users to manipulate their perspective through touch gestures for panning and zooming. These 3D visuals can be superimposed on real-world surfaces via augmented reality (AR) support for a richer sensory experience and more engaging interface.

We design *AnatoView* to be used by physicians as a supplement to their spoken explanation during the traditional informed consent process — offering an educational, highly visual, step-by-step supplement for the procedure being discussed — and do not encourage it as a substitution for a physician’s explanation. This is because the provision of information alone cannot constitute valid informed consent, which is predicated on communication and shared decision-making between patient and physician [19].
2 AnatoView: Application design and development

Informed by (a) our review of existing multimedia technologies for patient comprehension, (b) our understanding of the role of visuospatial cognition in medical comprehension, and (c) our interviews with healthcare providers on the deficits of conventional informed consent protocols, we designed AnatoView to improve patient comprehension via interactive 3D visualizations of medical procedures.

AnatoView incorporates features that prior multimedia interventions for informed consent have tested and found effective for improving patient comprehension. Like others, our application relies on paired delivery of 3D computer visuals (often animated) with descriptive text [20][21][22][23].

We propose a novel solution, however, in the form of an interactive user interface that allows users to manipulate these 3D visualizations: using touch gestures to pan, rotate, and zoom to areas of interest. Whereas previous multimedia interventions have all relied on non-interactive visualizations, we offer users the opportunity for learner-controlled perspective manipulation, which has been found (outside the context of informed consent) to contribute to “the successful integration of complex spatial information” [24] of medical procedures. By targeting visuospatial cognition — an important component of our study that remains untested among peer interventions, yet is ”central to understanding medical images” and procedures [25] — we develop a unique, focused approach for improving patient/layperson comprehension.

Additionally, a majority of peer multimedia interventions were designed to be viewed independently from the in-person informed consent meeting between the patient and physician: as a preparatory learning aid that patients access prior to meeting with a physician [20][21][22][23].

We diverge from this by designing AnatoView as a learning supplement to be used during informed consent. By providing discrete, step-by-step, sequential explana-
tions of medical procedures in AnatoView’s walkthrough feature, we enable direct integration of the intervention into the informed consent process. In meeting with patients, physicians can use the interface as a shared reference material. By using the controls for navigating between walkthrough steps, physicians can align the currently displayed step on the interface with the contents of their explanation: progressing forward or backward in the walkthrough at their own discretion. This allows laypersons/patients to digest information through multiple senses beyond just the auditory, forming connections between what is simultaneously heard and seen.
Table 2.1: Design guidelines for *AnatoView*

<table>
<thead>
<tr>
<th>Guideline</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Informative</td>
<td>Provides information re: medical procedures that is comprehensive and professionally sourced</td>
</tr>
<tr>
<td>Interactive</td>
<td>Offers interaction opportunities to users through intuitive touch gestures</td>
</tr>
<tr>
<td>Improves visuospatial cognition</td>
<td>Endows users with visuospatial awareness of medical procedures</td>
</tr>
<tr>
<td>Enables self-paced learning</td>
<td>Allows users to control the pace of their learning, spending as much time as individually needed to process information</td>
</tr>
<tr>
<td>Accessible</td>
<td>Presents textual information at a widely accessible (sixth-grade) reading level and visual information rendered to be accessible</td>
</tr>
<tr>
<td>Cost-effective</td>
<td>Can be realistically integrated into existing clinical workflows</td>
</tr>
</tbody>
</table>

Afterward, when the physician prompts the patient to ask any questions they may have, the layperson/patient has the opportunity to use *AnatoView* for themselves. The layperson/patient can revisit steps in the walkthrough corresponding to their sources of confusion, and play an active role in reinforcing their learning, at their own pace.

### 2.1 Design guidelines

In creating *AnatoView*, we developed a set of design guidelines, shown in Table 2.1.

### 2.2 Development of features

We implemented the following features in *AnatoView* to fulfill our defined specs.

#### 2.2.1 3D visualizations

To benefit users’ spatial cognition, which we posit is intrinsically tied to their comprehension of medical procedures, we display three-dimensional visualizations of the
anatomical structures relevant to the procedure. These visuals comprise 3D textured models that are high-resolution, medically accurate, and optimized for integration into our development platform.

We build our 3D models through a multi-step pipeline, summarized in Figure 2.1 and described below.

**Photogrammetry** To ensure that each model is medically accurate (per a generic representation of human anatomy), we perform photogrammetry on a physical anatomical model of the target subject (i.e. the cervical spine, a.k.a. neck) that is used to train medical personnel in academic medical centers.

Photogrammetry is a process whereby a three-dimensional mesh is reconstructed from a large library of two-dimensional images. We begin this process by assembling our image library: taking several hundred photographs of our physical model, intentionally varying angles while maintaining consistent environmental conditions (e.g. lighting, surrounding objects) between shots. The diversity in camera angles and the large amount of photos contributes to the robustness of our library, increasing the overall likelihood of procuring a successful 3D model through photogrammetry.

We provide this image library as input to our photogrammetry software. The software processes these photos. Through a step known as correspondence, it identifies matching features between pairwise images and triangulates them in 3D space to determine the depth of each feature. From correspondence, we obtain a comprehensive series of depth maps. Through a final step known as registration, we obtain the depth-coordinates from these maps, project them out of the calibrated camera, and generate a digital 3D mesh of the anatomical model.

**Retopology** Though it is useful for creating a medically accurate foundational mesh, photogrammetry does not produce performance-optimized meshes, nor does it produce infallible ones. The base mesh produced via photogrammetry had un-
necessarily high tri counts, which tends to compromise graphical performance and
yield suboptimally high computational and rendering costs. These graphical limita-
tions are especially stringent in mobile application development environments such as
ours. Additionally, photogrammetry struggles with capturing internal cavities (e.g.
holes) in physical objects — cavities that are prevalent in many anatomical mod-
els, with ours unexempt. Poor lighting conditions within these cavities, as well as
the general sparseness of visual information for these cavities, make them difficult
to adequately photograph. Our base mesh had many erroneously ‘closed’ holes that
required manual correction and refinement.

We made these corrections through retopologizing the base photogrammetric mesh
into a refined, performant, and usable model. After importing the mesh to our 3D
modeling software, we selected regions that were not geometrically complex enough to
warrant their initial polygonal resolution (i.e. density of tris), such as predominantly
flat planes and other simple polygonal shapes (i.e. cylindrical nerves). We then
reduced these tri counts, aggregating small tris into larger ones without any noticeable
loss in resolution or visual detail. We also identified sources of non-manifold geometry
such as overlapping edges and manually corrected them through a series of granular
editing operations.
Integration  Upon retopologizing and refining a mesh, we import it into our development platform. We assign it its proper texture and material, and position it in our scene. Medical instruments such as needles are positioned accordingly, to be maneuvered into anatomical injection sites in our sequential, step-by-step animations.

2.2.2 Animated walkthroughs

AnatoView’s walkthrough mode breaks down medical procedures into discrete, sequential steps. Each step is visualized in the interface as a 3D computer animation accompanied by a popup of descriptive text, which essentially operates as a transcription of what is spoken aloud by the physician administering the informed consent.

Animations  To create informative animated sequences, we coordinate interactions between our 3D models of anatomical parts and medical instruments. For our use case in the cervical medial branch block, we primarily use our cervical spine and spinal needle models. For all procedures, we ubiquitously use a generic human body model to position anatomical models (the cervical spine in the neck, in this case) within the body, lending context (an understanding of where a particular anatomy is located in one’s body) and sense of scale to users.
Figure 2.2: A variety of visual effects (VFX) are used to represent non-solid properties such as fluid or heat. Here, the gradual spreading of yellow (an abstractly representative color) throughout the region of the neck is used to represent the injection of a local anesthetic; the amount of spread approximates coverage of the locally numbed region.

Throughout our animations, we rely on several visual effects, i.e. shaders and lights, to simulate non-solid properties such as fluids and heat. We also employ an X-ray visual effect to render internal anatomies to be visible even through the body. (See Figures 2.2 and 2.3, respectively.)
Figure 2.3: An X-ray VFX shader is employed to render the anatomical region of relevance, the cervical spine, through the otherwise opaque “skin” of the generic body. When this “skin” is visible and opaque, the X-ray-shaded region remains ‘holographically’ visible (in orange). Note, also, the use of a VFX to represent the pain localized to the region, as also seen in Figure 2.2.

We implement these animations in our development platform through scripting a series of coroutines to trigger in a chain reaction, one after another. Coroutines allow us to specify timing parameters (i.e. how long we intend a certain movement to take, in terms of duration) and introduce dependencies between tasks’ start- and end-points. For instance, to visualize the injection of local anesthetic into the medial branch nerves, we animate our spinal needle model to perforate the skin of the neck and gradually move into the nerves that lie within. We then animate the medial branch nerves numbing over time — taking on a blue-hued appearance through the use of a visual effect. This effect combines a subsurface scattering shader applied to the nerves’ material with a back-facing directional light. Through coroutines, we predicate the beginning of this numbing effect on the ending of the needle’s injection animation. (See Figure 2.4.)

**Walkthrough controls** Users can navigate to the next step by pressing the ‘next’ button (a rightward arrow) and navigate to the previous step by pressing the ‘previous’ button (a leftward arrow). They are not obligated to finish watching the current
Figure 2.4: Through the use of coroutines in our development platform (Unity), we predicate the beginning of one animation on the ending of another. In this case, the needle ending its movement path (left) triggers the medial branch nerve to be ‘numbed’ through subsurface scattering VFX (right).

...step’s animated sequence before skipping to a different step. Although physicians, while using the interface, will wait for these sequences to finish before moving onto the next step, “patients” (i.e. laypersons adopting the patient role in the simulated informed-consent setting) are free to skip between steps. They are able to navigate with ease to steps they find confusing — spending more time reinspecting elements of the medical procedure that are subjectively higher-complexity, with less time spent on elements they have less difficulty understanding. By tapping on the ‘replay’ button that appears after an animation finishes, users are also able to rewatch animations as many times as they need. These features grant users agency over the AnatoView interface, allow them to attend to their own individualized learning needs, and empower them toward directing and pacing their own learning.
2.2.3 Viewport manipulation

Users are able to manipulate the viewport through touch gestures. (The more technical reality is that they are able to manipulate their perspective of a three-dimensional scene through rotating and scaling the objects within the scene; subjectively, this registers to users as identical to viewport manipulation.)

**Rotation** To perform a rotation around the y-axis, which we designate as the primary axis (i.e., the axis most relevant to obtaining perspective-dependent visual-spatial information), a user presses a single finger to the screen, holds it down, and drags their finger leftward or rightward, depending on the direction they would like to shift their perspective toward.

**Zoom** To zoom in or zoom out (technically implemented as scaling the three-dimensional scene), a user presses two fingers to the screen, holds them down, and ‘pinches’ those fingers either closer together or further apart. Respectively, this zooms out or zooms in on the three-dimensional scene. We include instructions for these touch gestures in the upper-left side of our interface.

**UI Sliders** As an alternative to these touch gestures, users can also manipulate their viewport through the rotation and zoom sliders. To certain users, these sliders may be more intuitive or easier to control. Their interactive handles are accompanied by labels that quantify the current rotation and zoom parameters: they range from $0^\circ$ to $360^\circ$, and $0\%$ to $100\%$ zoom, respectively.

**Resetting the view** Upon detection of changes to the viewport, a ‘Reset View’ button appears in the upper-left corner of the interface. Users may tap on this button to reset the viewport to its original perspective.
Augmented reality support

In *AnatoView*’s brief onboarding sequence, users may choose to enable or disable augmented reality in the viewport. If augmented reality is enabled, users will be able to see the models superimposed upon a physical, real-world plane of their choice. First, users are prompted to orient the camera of their device toward a well-lit and relatively unobstructed flat surface. Once a surface has been successfully recognized and scanned, users will be prompted to tap a location on the scanned plane to ’place’ the model. (See **Figure 2.6** for this AR onboarding sequence.) The model will then be positioned in real-world space for the duration of the *AnatoView* session. If the user walks around and moves while holding the device, the model will remain positioned in the same space; this allows users a tactile means of manipulating their perspective without using the touch-gesture viewport controls. (See **Figure 2.5**.)

![Figure 2.5: When using AnatoView’s viewport in augmented reality, the loaded procedure’s 3D models are superimposed onto a physical, real-world, horizontal plane of the user’s choice. While holding the device that the AnatoView application is being run on, users may physically maneuver around the plane to adjust their perspective of the 3D visuals.](image-url)
Figure 2.6: The augmented reality (AR) onboarding sequence for AnatoView first prompts users to find a physical flat surface with their camera (top-left). It then prompts them to tap the recognized surface (top-right). Once the model is placed (bottom-left), the user sees the preview screen for the associated procedure and can proceed to the educational module (bottom-right).
3 User study: Design and methodology

To test the effectiveness of AnatoView on improving layperson comprehension in the context of informed consent, we conducted a randomized controlled trial with \( n = 15 \) laypersons as participants.

3.1 Recruitment

The study was advertised through a series of printed posters distributed in high-traffic public areas at two locations: (1) Dartmouth College, and (2) Dartmouth-Hitchcock Medical Center (DHMC). Several professors also helped publicize the study by relaying details to students enrolled in ongoing courses. Interested parties then scanned QR codes or followed links to an interest form that we created to determine eligibility for the study. The form prompted respondents to indicate whether or not they were a native or multilingual English speaker (i.e. possessed native-level proficiency in English comprehension). It also asked them to describe the extent of their prior knowledge or experience with chronic pain treatment, if applicable. A total of 22 responses were collected from the interest form and reviewed to determine respondents’ eligibility.
### Table 3.2: Participant groups, as per *between-subjects* study design

<table>
<thead>
<tr>
<th>ID</th>
<th>Category</th>
<th>Intervention received</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>Control</td>
<td>Traditional informed consent process with verbal explanation</td>
</tr>
<tr>
<td>B</td>
<td>Experimental</td>
<td>Informed consent process with verbal explanation, supplemented by <em>AnatoView</em>’s strictly 3D interface</td>
</tr>
<tr>
<td>C</td>
<td>Experimental</td>
<td>Informed consent process with verbal explanation, supplemented by <em>AnatoView</em>’s AR interface</td>
</tr>
</tbody>
</table>

In determining eligibility for participation in the study, we defined the following inclusion criteria: (a) participants had to be native or multilingual English speakers, and (b) participants had to possess no prior knowledge or experience with chronic pain treatment. As a result, we controlled for English literacy and familiarity with the subject matter of our use-case (specifically, lack thereof).

### 3.2 Study design

We designed a mixed study, evaluating our primary outcome — participant/layperson comprehension of a medical procedure — both between subjects and within subjects.

#### 3.2.1 Between subjects

Using an online random number generator, participants were randomized by numerical ID into one of three groups: (1) a control group undergoing the standard informed consent process, (2) an experimental group undergoing the informed consent process using *AnatoView*’s strictly 3D interface as a learning supplement, and (3) an experimental group undergoing an adjusted informed consent process, using *AnatoView*’s AR interface as a learning supplement. We labeled these groups A, B, and C, respectively.
Table 3.3: Data collection timepoints for each group, as per *within-subjects* study design

<table>
<thead>
<tr>
<th>Timepoint</th>
<th>Data collected</th>
</tr>
</thead>
<tbody>
<tr>
<td>T1</td>
<td>Pre-intervention score on a 10-question comprehension assessment</td>
</tr>
<tr>
<td>T2</td>
<td>Post-intervention score on a 10-question comprehension assessment</td>
</tr>
</tbody>
</table>

3.2.2 Within subjects (across timepoints)

Data was collected for each group at two timepoints: before receiving the assigned intervention (T1), and after receiving the assigned intervention (T2). At both timepoints, participants were administered a comprehension assessment of the use-case medical procedure to quantitatively measure their understanding. (See ‘Pre-intervention comprehension assessment (T1)’ and ‘Post-intervention comprehension assessment (T2)’ for more details.)

3.3 Study methodology and protocol

Below, we describe the methodology of our study. (See Figure 3.7 for a flowchart.)
3.3.1 Onboarding survey

Each session began with the participant completing a digital onboarding survey. Participants were informed that the survey would take no more than 5 minutes to complete, and were then given a laptop with the survey loaded onto a browser.

Participants from all groups provided preliminary background information: their name, age, gender, and education level. For respondents who were not actively students, we specified this to be their highest completed level of education, and for respondents who were active students, we specified this to be their level of ongoing education. We collected these demographics to account for independent variables that have demonstrably affected comprehension rates in prior studies.

Participants from all groups then self-reported their relationship with visual learning: completing a user-efficacy self-evaluation, which we administered through two matrix tables of Likert scales. In the first table, participants were prompted to indicate their level of agreement with a series of statements regarding their relationship with visual learning, such as “I consider myself a visual learner” and “The use of visual aids enhances my understanding of complex concepts.” In the second table, participants rated how helpful they found visual learning to be for accomplishing a set of tasks, such as “Understanding complex information” and “Retaining information for longer periods of time.” They then finally rated their confidence in “see[ing] a 2D image (i.e. a photo) of an object” and “mentally visual[izing] that object in 3D space.” We collected these qualitative self-reportings to account for potential predictors of improvements in medical comprehension from those who are confident in their spatial cognition, i.e. ability to comprehend, retain, and communicate with visual information.

Lastly, we prompted participants from Group C to indicate their prior familiarity with augmented reality technology through a series of Likert scales. We asked respondents to self-report their familiarity with augmented reality technology, such as how often
Figure 3.7: The methodology for our study. Participants were enrolled, then recruited if they passed our defined set of eligibility criteria. They were then allocated into three different groups (A, B, or C) — after which they receive a pre-intervention comprehension assessment (consistent across all groups), an intervention (control or experimental), and a post-intervention comprehension assessment (consistent across all groups).
they use AR, how comfortable they are with AR usage, and attitudes toward AR. This was done to account for potential predictors of improved comprehension among Group C’s participants — as those who have previously used augmented reality applications/devices and are familiar with the superimposition of three-dimensional objects in real-world space may be more adept at manipulating these objects and parsing visual information from them.

3.3.2 Pre-intervention comprehension assessment (T1)

We administered a 10-question multiple-choice comprehension assessment on paper to all participants after completion of the onboarding survey, prior to any intervention (i.e. any iteration of informed consent). The comprehension assessment tests for understanding of our use-case medical procedure: that is, critical elements of the cervical medial branch block (CMBB), including its primary diagnostic purpose, the medication typically injected during the procedure, and the names and positions of key anatomical landmarks targeted as injection sites during the procedure. Participants were given 5 minutes to answer all 10 questions, and were informed that they did not have to use all of their time. No participants spent the maximum 5 minutes to complete the assessment; on average, they used 3 minutes and 7 seconds. We predicted that this would be the case, and still chose to allot a generous amount of time to reduce the likelihood of participants incurring test-taking anxiety or stress that would confoundedly hinder performance.

We administer this pre-intervention assessment to establish a baseline for a participant’s preliminary ‘understanding’ of the medical procedure, accounting for the possibility of background knowledge that was not detected during enrollment — as well as simple medical and/or test-taking intuition that may guide even uninformed participants to answer certain questions correctly. We preface the pre-intervention assessment by disclaiming that participants are not expected to be familiar with the medical procedure it tests on; we encourage them to provide answers to the best of
their ability.

The assessment’s questions and answers were written by the chronic pain specialist on our team, checked against multiple sources for factual correctness, and revised through multiple iterations to match a sixth-grade reading level.

### 3.3.3 Intervention

We administered three different interventions, each corresponding to one group. All interventions were structured as a simulated informed consent discussion with a licensed physician (specifically, a chronic pain specialist), held face-to-face in a quiet, controlled, indoor environment at one of two locations: Dartmouth College (one consistent room in the computer science building) or Dartmouth-Hitchcock Medical Center (one consistent room in the health sciences library). Location was determined based on the assisting physician’s availability as well as the participant’s preference.

The controlled intervention consisted of the traditional informed consent process, with two-dimensional printouts of images used to supplement the spoken explanation. The use of 2D images as learning aids is not standardized across public healthcare institutions’ clinical workflows, but it is a common choice made by physicians in an attempt to endow patients with a visual understanding of the procedure. Physicians will commonly locate these reference images through online searches and display them on a monitor to the patient, pointing at regions of interest mentioned in their explanation. We chose three reference images to use in our controlled intervention, reproduced in Figure 3.8.

In explaining the procedure, each physician followed our informed consent script. This ensured standardization in the content, depth, and quality of the explanation across sessions. Excluding time spent on patient-physician dialogue (answering patients’ questions), this explanation took 2 minutes and 49 seconds on average.
Figure 3.8: Images of the cervical medial branch block that were found through a popular search engine, then provided to the control group, Group A, in a simulation of the traditional informed consent process. Although images (or any other learning supplements, for that matter) are not standardized for use across IC processes, physicians we preliminary interviewed when formulating our research question testified to many instances of displaying online image results from a search engine to attempt to help patients (visually) understand the procedure.
Experimental groups received an informed consent process consisting of the spoken explanation and the *AnatoView* application as a supplement. Physicians controlled the application's walkthrough by navigating through its steps with the arrow buttons and synchronizing their explanation with the walkthrough such that the displayed text and animation reflected what was spoken aloud at any given moment. Physicians also manipulated the viewport: zooming in on regions of interest for each step, rotating the three-dimensional objects to obtain an optimal, unimpeded view of these regions, and pointing at the (oft-labeled) anatomical landmarks and medical instruments in these regions. These viewport manipulations were also scripted for physicians and standardized; physicians were instructed against using arbitrary, spontaneous, and potentially confusing touch gestures.

After the explanation, physicians invited participants to ask any questions they had regarding the medical procedure. If questions were raised, they were all answered before proceeding to the post-intervention comprehension assessment.

After resolving these questions, we gave participants in the experimental groups the opportunity to interact with *AnatoView*. We encouraged them to use the application on their own, if they wished to; participants were allowed to experiment with controlling the viewport and revisiting whichever steps in the walkthrough that they wished to. Though we did not explicitly prompt it, several participants asked additional questions that they had not previously raised with the physician during this (optional) participant-controlled interaction sequence. The physician answered these additional questions and re-verified that the participant had resolved all questions before completing the intervention.

### 3.3.4 Post-intervention comprehension assessment (T2)

A second comprehension assessment was then administered to participants following completion of the intervention. This assessment is identical to the first one, comprising the same set of 10 multiple-choice questions regarding the cervical medial branch block
Later, in evaluating the data we collected, we calculate the difference in score (that is, the number of correct answers, out of 10) between each participants’ pre-intervention and post-intervention assessments, and use it as a quantitative measure of improvement in their comprehension.

3.3.5 Offboarding survey

To complete the session, participants answered a digital offboarding survey on a provided laptop. We collected qualitative data from all participants on their subjective experience with the informed consent process, asking participants to rate their level of agreement with the statements of another matrix of Likert scales, i.e. “The purpose of the treatment/procedure was clear to me,” and “I feel better prepared for the 10-question comprehension assessment after learning about the treatment/procedure vs. before.” This marked the end of the survey for participants in the control group.

Participants in experimental groups, however, were also prompted to consider their experience using AnatoView through an additional two Likert matrices. In the first, we surveyed for user engagement: providing a set of statements regarding users’ general feelings toward the application, such as “I felt engaged while using the app” and “I found using the app to be straightforward and easy to understand,” and asking users to indicate their level of agreement with each. In the second, we surveyed users’ experiences in relation to their medical comprehension. Statements such as “I had an easy time connecting what I saw in the app to what I heard the physician explain to me” were generalized across offboarding surveys for both experimental groups. However, each group was also provided with statements specific to the version of AnatoView that they were assigned to use; for instance, Group B’s “Seeing the treatment/procedure visualized in three-dimensional (3D) space helped me understand it” was rewritten to “Seeing the treatment/procedure visualized in Augmented Reality (AR) space helped me understand it” for the survey provided to Group C.
Table 4.4 summarizes the demographics of participants. The majority were college-aged students; 9 were undergraduate students and 5 were graduate and PhD students. One participant was a nurse at Dartmouth-Hitchcock Medical Center. The average age among participants was 23.7 years. 9 participants were women, 5 participants were men, and 1 participant was non-binary. Groups A (control), B (experimental-3D), and C (experimental-AR) all contained 5 participants each.
5 Results and conclusions

5.1 Medical comprehension

5.1.1 Effects of IC interventions on medical comprehension

To quantitatively measure our primary outcome — the effectiveness of an informed consent intervention on a layperson’s understanding of a medical procedure — we calculated the difference between participants’ pre-intervention scores at T1 and post-intervention scores at T2 on the cervical medial branch block comprehension assessment.

Below, we discuss evaluating this outcome both within groups and between groups.

Performance on comprehension assessments within groups

To evaluate the effectiveness of a given intervention within groups, we compared the average score of a group’s participants at T1/pre-intervention with their average score at T2/post-intervention. We display these differences across timepoints in Figure 5.9.

To then evaluate the statistical significance of these improvements in average score across T1 and T2 within groups, we employed the Wilcoxon Signed-Ranks Test using a one-tailed hypothesis (i.e. one-sided test, to specifically measure improvement in score) and an $\alpha$ value of 0.05. We found the improvement in average score among every group to be significant, wherein Groups A ($z = -2.023$), B ($z = -2.023$), and C ($z = -2.023$) all yielded z-scores below the critical value of $z = -1.645$ at $\alpha = 0.05$. This indicates the following:

5.1.1.1 The introduction of any informed consent intervention, whether supplemented by a multimedia digital learning aid or not, is meaningful for
laypersons’ medical comprehension. Despite numerous shortcomings identified in the conventional informed consent process, it is evidenced that the process still fulfills its intended purpose. This reifies our precept that the public healthcare our target user base receives should be improved through augmenting the informed consent process rather than wholly discarding it or wholly redefining standards on medical consent. This corroborates Schenker et al.’s 2017 systematic review on prospective improvements to informed consent. The review posits that, in spite of “overwhelming evidence of inadequacies in the informed consent process,” continual “efforts to improve the process” are consistently meaningful for patients’ healthcare [17].

Performance on comprehension assessments between groups

To compare the effectiveness of different informed consent interventions to each other, we studied the mean improvement in comprehension assessment scores between groups. We display this data in Figure 5.10 and report the following findings.

5.1.1.2 Those who used AnatoView as a learning supplement demonstrated significantly greater improvements in medical comprehension than those who did not. The average change in score among users (4.3) was ≈54% higher than the average change in score among non-users (2.8). (Note that no participants scored lower at T2/post-intervention than T1/pre-intervention, so any reference to change in score is synonymous with improvement in score.) Using the Mann-Whitney U Test (one-tailed hypothesis, $\alpha = 0.05$), we determined the difference in improved comprehension between users and non-users to be statistically significant ($p = 0.04$).

5.1.1.3 At the same time, AnatoView’s strictly 3D interface slightly improved participants’ medical comprehension more than its augmented reality interface — but not by a significant amount. When comparing between the two experimental groups, Group B (averaging an improvement of 4.8) outperformed
Figure 5.9: The average score among each group’s participants at T1/pre-intervention and T2/post-intervention. The increase in score between timepoints for all groups provides evidence that all interventions were, at minimum, significant for improving comprehension.

Figure 5.10: The mean improvement (between T1/pre-intervention and T2/post-intervention) in comprehension assessment score across all groups. Overall, users outperformed non-users, with Group B users also outperforming Group C users on a more granular level.
Group C (averaging an improvement of 3.8) by ≈26%. Using the Mann-Whitney U Test, we did not find this difference to be statistically significant. It nonetheless motivates further discussion on (a) why AR features may benefit certain users less than others, and (b) how we can best recognize these users, accommodating their individualized needs. We explore this in Future work.

5.1.2 Influence of visuospatial cognition on medical comprehension

Below, we report our findings on visuospatial cognition as it relates to medical comprehension. Visuospatial cognition was qualitatively measured through (a) observational evidence from user behavior during sessions and (b) anecdotal evidence from user testimonies, collected from the offboarding survey and feedback conversation.

5.1.2.1 Users reported the 3D visualizations to be comprehensible and helpful for their understanding. In responding to the offboarding survey as well as describing their user experience afterward, several users testified to finding the animated 3D visualizations to be “visually clear and easy to understand” (P13), “helpful [for] see[ing] what was actively happening” (P15), “intuitive” to interact with (P7), etc.

5.1.2.2 Users found the 3D visualizations helpful for guiding their focus and attention while learning. One user, P8, specifically reported feeling more focused and attentive in their learning through the rendering of the anatomical region centrally involved with the procedure. Seeing the cervical spine region in the absence of “too much distracting detail [from] other anatomy” (P8) was a welcome departure from traditional medical visualizations, such as radiological/fluoroscopic images, that do not typically filter out or exclude neighboring regions on the basis of relevance. This indicates that our decision to (a) exclude non-relevant anatomical regions, while (b) including a generic display of the human body, in which the relevant anatomy is
visibly positioned, was successful for endowing users with a contextual sense of where the region of relevance was spatially positioned within the body, all the while not detracting from their attention on the region of relevance.

5.1.2.3 The importance of visuospatial cognition on medical comprehension was felt by users, several of whom explicitly mentioned perceived benefits from AnatoView’s 3D visualizations. Users testified to the difficulty inherent to visualizing procedures from spoken instructions alone, and understood this to be an obstacle that would have negatively affected their overall comprehension. P7 found the application “definitely useful for, like, understanding where stuff’s physically gonna happen.” Elaborating on this response, they said: “I dunno... you can tell me where stuff is gonna happen and... I don’t have much understanding of the anatomy of my own body, which I guess is my own problem, so I won’t get much out of that. But, like, what a doctor knows is much more than what a normal person knows, and having a visual representation is very useful for that [bridging between different expertise levels].”

5.1.2.4 This visuospatial cognition, according to users, would otherwise be unobtainable through traditional 2D instructive images and videos, which are frequently difficult to understand. Citing previous experiences with these materials, users reported finding them to be inadequate for medical comprehension as laypersons. Regardless of how formally assembled the images were — whether they came in the form of a “textbook” on “how this procedure gets done” (P11), or as a “random drawing” made by a licensed physician during informed consent (P8) — users felt limited in their understanding. P8, in complaining about the “random drawings” (see quotation from earlier), identified two limitations commonly found in 2D visuals: (1) an absence of visual focus, i.e. an inability to clearly distinguish between relevant and non-relevant anatomical regions (“where I’m supposed to focus on”), and (2) an absence of informative context (“what I’m supposed to be looking at”).
i.e. a lack of labels or sense of perspective (Where am I, the viewer, looking toward? Looking from?). These testimonies corroborate the limitations of traditional learning materials identified in [Spatial Cognition in Medicine], where “diagrams are unavoidably restricted to two dimensions, generally entail only cardinal views, and bear little resemblance to real anatomy.” We address these limitations with AnatoView through the use of 3D visuals as well as animated labels and indicators, which attract and guide users’ attention to the anatomical regions relevant to a given step.

In discussing the inadequacies of traditional 2D visuals, certain users drew from past experiences with medical procedures; they testified to finding AnatoView’s 3D visuals to be more comprehensible than the 2D visuals they had been given leading up to treatment — which were inaccessible, frustrating, and difficult to comprehend. P2, who reported having “knee surgery a while ago,” had “looked up a bunch of images online” by querying the procedure “but couldn’t comprehend much from them.” These images tend to be “cross-sectional diagrams and images” that lack a sense of depth, dimensionality, or perspective; flatten 3D anatomies into 2D orthographic projections; and are thus difficult to comprehend.

Another user, P10, shared a similar experience as P2. To accurately and wholly represent the depth of P10’s experience, we reproduce our transcription of the testimony in its entirety below:

So I had a surgery... I had an ovarian cyst surgery. Before I got diagnosed, people did a lot of tests and then I did not have... I wasn’t actually diagnosed for a very long time. Then even after I was diagnosed, my doctor was like, ”Oh, you have this.” And then he used to point out things to me on the screen. But then the ultrasound screen is very hard to look at. He’s like, ”This is the issue.” But it’s like, how do I understand? Because frankly, I don’t see the issue at all. I think I would’ve really appreciated having this [application] — I think, more clear communication about what is going on — not only because I’m worried about my health, but also, it’s interesting. And just understanding this is very, I think, both helpful... and relieving, and interesting, for the patient. They don’t feel so lost.

P10’s testimony corroborates Baum 2006’s finding that a patient’s satisfaction is
highly dependent on how well-informed they feel about their medical diagnosis and proposed treatment [26]. Moreover, P10 was not alone in expressing an emotional response to the perceived comprehensibility of a visualization. Whereas P10 felt negative emotions in response to indecipherable 2D visuals, P14 felt positive emotions in response to AnatoView’s 3D visuals; though they did not report a personal medical history, they found that “actually getting to see what happens [during the procedure]” through AnatoView’s interface “is comforting.”

5.1.2.5 Through examining these users’ testimonies, we hypothesize a dependency chain of subjective experiences. How visually and spatially informed a person feels contributes to how well-informed they feel about the procedure overall — which, in turn, contributes to how supported or unsupported they feel. The depth of P10’s anecdote, P14’s statement, and the hypothesis we form therein, motivates future work on the effect of AnatoView on patients’ subjective experiences: how safe or frightened they feel, in response to the adequacy of their information and healthcare.

5.1.2.6 Our belief in the importance of visuospatial cognition to laypersons’ medical comprehension is reified by the above findings. We conclude that current limitations in traditional 2D visuals — including textbook images, cross-sectional diagrams, CT/MRI/X-Ray/ultrasound images, as well as physicians’ quick, utilitarian illustrations (made during IC to attempt to supplement a spoken explanation) — are difficult for laypersons to interpret, focus on, and comprehend. Patients, for whom these medical images are most relevant, feel lost, frustrated, and upset by the confusing nature of these 2D visuals. However, exposure to 3D visuals through AnatoView benefits users’ comprehension. Additionally, certain testimonies support our hypothesis that AnatoView may be capable of benefiting, or may already benefit, an individual’s subjective and emotional experience with a procedure — a promising area of study for future work.
5.1.3 Relationship between subjective knowledge and objective knowledge

To evaluate subjective knowledge, how well-informed a participant feels they are, we prompted all participants to indicate their level of agreement with the prompt, “Overall, I feel well-informed about the treatment/procedure” (OFF_S1.Q5). For each group’s responses, we found no statistical significance between any groups in how they responded to feeling well-informed, suggesting that the intervention a group received, i.e. whether the group used or did not use AnatoView, had no significance on how well-informed that group’s participants then felt about the procedure.

5.1.3.1 Participants, regardless of intervention, were not reliable judges or reporters of how well-informed they actually were. Among all participants, we found little to no correlation between subjective knowledge and objective knowledge, i.e. how well-informed a participant feels had no bearing on their improvement in the comprehension assessment between T1 and T2.

This finding calls into question the use of a patient’s signature as an indication of consent in traditional IC processes. Patients sign their consent when they believe they are sufficiently informed of the procedure. However, if patient belief and patient subjectivity is not synonymous with objective patient comprehension, the patient signature becomes an unethical means of obtaining informed consent. While our intervention focuses on resolving inadequate patient/layperson comprehension in informed consent, and does not propose a solution to this inadequacy in determining informed consent, we find it worthwhile to encourage further interrogation of this inadequacy nonetheless.
5.2 Communicativity

When we prompted participants to ask questions about the procedure, we recorded both the amount of questions asked and the time spent on questions and answers between the participant and physician. We display these individual results, as well as averages we calculated to aid comparison between groups, in Figure 5.11.

Evaluating this quantitative data, alongside observational and anecdotal evidence collected from users during our sessions, led us to conclude the following.

5.2.0.1 AnatoView users were significantly more communicative than non-users. On average, users asked a greater amount of medical questions than non-users, averaging 4.4 compared to non-users’ 0.4. Using the Mann-Whitney U Test ($\alpha = 0.05$; two-tailed hypothesis), we found this difference between groups to be significant ($p = 0.01$). Additionally, when compared to non-users, users were 2.25 times likelier to ask any questions at all. Whereas nine out of ten AnatoView users asked questions to clarify their understanding — ranging between a maximum of 12 questions (P10) and a minimum of two (P11, P14) — three out of the five non-users did not ask any questions. Of the two that did, both asked only a singular one. For instance, P1 (Group A) did not initially raise any questions when prompted to. Instead, they responded that they were still “trying to process it [the procedure]” and “[did not] really know what to ask.” It was after roughly a minute had passed, wherein we left the participant to their thoughts, did they ask, “This is a procedure that has been done before? . . . That’s very interesting.”

Asking more questions overall increased the length of interactions between the layperson and physician. The control group averaged 0 minutes and 15 seconds among all participants (0 minutes and 39 seconds among the 2 who did speak with their physician), whereas the two experimental groups averaged 5 minutes and 59 seconds (Group B) and 2 minutes and 54 seconds (Group C), respectively. With an accumu-
Figure 5.11: Communicativity between groups, measured by the number of questions a participant asks regarding the use-case medical procedure (i.e. cervical medial branch block) of their physician.
lated average of 4 minutes and 27 seconds, experimental group users overall spent
1680% more time communicating with their physician than control group users.

We now explore the contributions of specific factors to these disparities between users
and non-users in communicativity. Through comparisons with non-users, who did not
receive these benefits, we identify two categories of benefits on users’ communicativity:
one that helped users realize their questions through understanding the procedure
better, and one that helped users better articulate their questions through providing
non-verbal, and more accessible, communication modalities.

5.2.1 Realization of questions

5.2.1.1 Users, unlike non-users, had a learning supplement that allowed
them to comprehensively review the procedure after the spoken expla-
nation. Non-users were asked, *Do you have any questions about the procedure?*. However, users, in conjunction with being prompted to resolve questions, were also
prompted to use *AnatoView* if they wished to. As a result, users were given the
unique opportunity to navigate between steps in *AnatoView*’s walkthrough without
the physician oversight from before. They could review the procedure at their own
pace: navigating to steps that they found initially difficult to comprehend.

5.2.1.2 Many users realized — and resolved — questions that arose only
during this review, when they could learn at their own pace. The amount
of questions that users asked immediately after the physician’s spoken explanation
tended to be non-exhaustive, and several users came up with additional questions
afterward only when engaging with the application themselves. Through this review,
users had additional opportunities to come up with questions: a second window of
opportunity to discover and resolve lingering sources of confusion. This self-direction
of the learning process was recognized positively by users; P12 stated that they ”liked
how you [the physician] explained it first and then let me play with it [the application],
letting me pause where I wanted to pause and process things." To this, P12 attributed a greater ability to ask questions. This brings us to the following additional set of findings.

**Alongside the ability to realize more questions, users were able to resolve more questions as well.**

**5.2.1.3 While using *AnatoView*, users, unlike non-users, could communicate questions at will; resolving them, in other words, with greater immediacy.** For not only was P12 able to "pause where I wanted to pause and process things," they were also "able to ask questions as they came up to me" — which they also expressed appreciation for.

Although no participants were expressly forbidden from asking questions during the physician’s spoken explanation, it is likely that participants either assumed that they were obligated to wait until the explanation’s completion, or simply chose to — perhaps thinking it rude to interrupt. In other words, non-users perceived one window of opportunity to ask questions; when they were prompted to, following the explanation. Users, however, perceived two windows of opportunities to ask questions; when they were prompted to, post-explanation, and while they were using *AnatoView* to review information at their own pace.

**5.2.1.4 Users’ ability to resolve questions became divorced from their ability to retain information from the physician’s explanation; however, non-users were implicitly required to retain this information to ask about it.** Given the frequency with which users raised questions while using *AnatoView* — questions that they had not raised directly following the physician’s explanation — we hypothesize that all participants, regardless of IC intervention, were not able to exhaustively resolve all sources of confusion immediately following the explanation. We posit that all participants experienced difficulties with remembering sources of
confusion after a learning experience that was not self-paced. However, any shortcomings in what users remembered (or did not remember) to ask were accommodated by using AnatoView at their own pace. It follows that non-users’ shortcomings in memory were not accommodated due to the absence of this learning supplement — which ended up serving as a conduit for both (a) improving the initial delivery of information and (b) reviewing it. As a result, non-users’ communicativity was strongly inhibited.

5.2.2 Articulation of questions

5.2.2.1 For all participants, the presence of medical jargon (i.e. the names of anatomical landmarks and procedures) made verbalizing questions difficult. Participants frequently spoke with interrupted speech, pausing and stuttering while asking questions in a clear deviation from their usual speech patterns. During these pauses, we can infer that participants were recollecting medical information (i.e. remember an unfamiliar medical term) or considering the phrasing of their question.

5.2.2.2 However, AnatoView provided a shared context between users and their physician, affording users more leeway in verbal communication. To begin, users were not penalized for using ambiguous references, which frequently emerged through their questions. We recorded many users using unspecific references to an “it” or a “that” in lieu of precise names for anatomical landmarks (i.e. “medial branch nerve,” “facet joint”), the procedures performed on them (i.e. “cervical medial branch block,” “radiofrequency ablation”), and so on. For instance, P13 (Group C) asked 5 questions across a total of 7 minutes and 28 seconds of communication with their physician, two of which were phrased ambiguously: (1) “So it’s to diagnose... it [pain from the facet joints]? Er...”, and (2) “So it’s [the radiofrequency ablation (RFA) procedure that destroys the medial branch nerves] just applicable in the neck...?” (Ambiguous references are bolded for emphasis, with context included...
Similarly, it was common for users to ask questions using shortened or abbreviated medical terms: saying “neck” instead of “cervical spine,” “dye” instead of “contrast dye,” and “heated needles” instead of “radiofrequency ablation.” For instance, P15 (Group C) asked three questions across a total of 2 minutes and 10 seconds of Q-and-A time, one of which was, “And the dye is for the . . . the dye is to make sure that, the — the inner anesthetic — is not . . . taken up [by the blood vessels in the area]?" (Shortened terms are bolded for emphasis, with additional context between brackets.)

5.2.2.3 In spite of ambiguous phrasing or abbreviated language, there was a mutual understanding between participant and physician that, at any given moment, the participant was referring to whichever contents were actively displayed on the AnatoView interface. The physician could therefore connect ambiguous references to what was simply visible on a shared device’s screen and answer these questions with ease.

5.2.2.4 Users were also afforded attractive alternatives to verbal communication, in the form of tactile communication (i.e. using physical gestures to indicate a subject) and visual communication (i.e. referring to a subject by an identifying visual characteristic such as color in lieu of a formal name). Being able to reference AnatoView’s 3D visuals helped users formulate their questions — expressing their inquiries through what they saw on the interface in lieu of medical jargon they struggled to retain. Users could point to anatomical landmarks that confused them, and ask questions to help identify them and/or their relevance in the procedure. For instance, in reference to the nerve root, P10 asked, “The yellow part [points to screen] is the spinal cord, right?” P6 had a very similar question, and articulated it through similar means: “The yellow component [points to the screen] — is that the spinal cord?” (Emphasis of an identifying visual characteristic being
used are italicized; tactile gestures that users made while speaking are transcribed in brackets.) In a later question, P10 also asked, “Does this only happen this way, like, just this side of the body?” while gesturing: tracing their finger down one side of the cervical spine. (Note, also, the use of ambiguous references that are made comprehensible through shared context.) Our observational data indicates that users were able to circumvent the use of medical jargon by simply referring to AnatoView’s visual interface.

5.2.3 Significance of communicativity

Ultimately, the frequency with which users communicated and resolved their confusions, compared to the infrequency of non-users asking any questions at all, indicates that AnatoView helped users take a more active role in their learning. This brings our experimental informed consent process closer to its intended purpose — of creating an environment for shared decision-making between patients and practitioners, in which patients have agency in their own healthcare.

5.3 Engagement

To measure how engaged participants felt while learning about the medical procedure during their administered IC intervention, we prompted participants to self-report their engagement in our offboarding survey. Participants indicated how much they agreed with the prompt, “I was engaged while learning about the treatment/procedure,” through a 1-5 Likert scale with verbally formatted options — where ‘Strongly disagree’ corresponded to a 1 and ‘Strongly agree’ corresponded to a 5. To enable quantitative evaluations of engagement, we converted responses to a numeric format. We display an overview of these responses in Figure 5.12 and discuss our findings below.

AnatoView users, whose medical comprehension was supplemented by the application, felt significantly more engaged than non-users in their own learning. All ten
Figure 5.12: Users self-reported how engaged they felt while learning about the medical procedure by choosing from a 1-5 qualitatively formatted Likert scale: ‘Strongly agree,’ ‘Agree,’ ‘Neutral,’ ‘Disagree,’ or ‘Strongly disagree.’ Note that all five Group B users reported feeling maximal engagement, i.e. responded ‘Strongly agree’ to the prompt.

Users reported feeling engaged, with two (20%) answering ‘Agree’ and the remaining eight (80%) answering ‘Strongly agree’; no users disagreed with, or were even ‘Neutral’ toward, feeling engaged. It is worth noting that Group B users unanimously expressed maximal feelings of engagement, as 5/5 (100%) answered ‘Strongly agree.’ (Group C users also unanimously indicated feeling a degree of engagement, but did not consistently report maximal engagement; we discuss this in further detail in ‘Effect of augmented reality features on user engagement’ below). Conversely, a majority of non-users, i.e. three out of five (60%), did not indicate feeling engaged. They instead felt ‘Neutral’ toward the statement. Using the Mann-Whitney U Test with $\alpha = 0.05$ and a one-tailed hypothesis, we found this difference in self-reported engagement between users and non-users, i.e. between experimental and control groups, to be significant ($p = 0.02$).
5.3.1 User engagement (UE)

To examine these disparities in how engaged users and non-users felt while learning, we now focus on the User Engagement (UE) results — collected through the UE offboarding questions for our experimental groups — as well as anecdotal and observational data collected from our sessions. Below, we discuss how our application affected engagement in the IC process; we organize our findings by several criteria from O’Brien’s refined 2018 User Engagement Scale (UES) [27]

Perceived usability (PU)

Users were prompted to indicate their level of agreement with two statements measuring perceived usability (PU): how much agency and control they felt in their interactions with the interface, and how much effort they felt had to be expended to accomplish these interactions.

In response to the prompt, “I found using the app to be straightforward and easy to understand” (S2.A.Q2), users were evenly divided between ‘Strongly agree’ (5/10) and ‘Agree’ (5/10). In response to, “I enjoyed physically interacting with the device (iPad) the app was displayed on” (S2.A.Q4), 5/10 responded ‘Strongly agree,’ 4/10 responded ‘Agree,’ and one respondent reported feeling ‘Neutral.’ There was no significant difference between Groups B and C in these responses, indicating that the presence or absence of augmented reality features did not significantly influence how responsive or usable the interface felt to users.

5.3.1.1 Users found the application intuitive, and the usability of the interface contributed to their delight. In response to the open-ended question, “Was there anything that delighted you while using the app? If so, what was it?” (OFF_S2.C.Q1), users described the application as “very straightforward” and “really intuitive to use” (P11), as well as “wonderful” for allowing them to “interact with the learning process” and play an active role in seeking out information (P10).
Several users also cited specific interactions as sources of enjoyment. P6 wrote that they “loved being able to interact with the procedures (going forward and backward, zooming in and out, etc.).” These two features — navigating between steps of the walkthrough, and manipulating the 3D viewport — were well-received by other users as well. Regarding the former, P14 also “liked the step by step nature of the explanations and the ability to go back and forth between steps.” Regarding the latter, P9 specifically mentioned the slider controls in the viewport, writing that “the scale bar indicating rotation degree and magnification was intuitive” and delightful.

However, several users found it difficult to understand when the touch gestures for manipulating the viewport could or could not be used. P9 found this to be problematic when they were still familiarizing themselves with the application’s controls, writing that “a few times it was hard to tell when the animation stopped and when I was allowed to interact with the app, but I figured it out pretty quickly” after repeated exposure. P15 corroborated this, characterizing the touch gestures as “a little unintuitive, and locked during animations.” For these users, it was not intuitive for the viewport manipulation controls to be disabled while the animation was still playing. It is possible that these users were interested in rotating and/or zooming their perspective to focus on a feature of interest the moment it was brought to their attention through the ongoing animation. It stands to reason that the grayed-out viewport sliders and instructions were not sufficient for informing users of the disabled viewport controls — it may be helpful to include an explicit demonstration of when these controls can be used in a tutorial sequence. Additionally, it may be worthwhile to experiment with allowing users to manipulate the viewport during ongoing animations in future application development and testing cycles.

5.3.1.2 One user brought an accessibility concern to our attention, finding the controls for navigating between steps in the walkthrough to be difficult to see. Although P6 found “the UX [user experience]” to be “really good” — noting that “in terms of hierarchy, it’s really clear — what action you’re supposed to perform
on each page,” they noted that “the forward and backward buttons” for moving to the next and previous steps, respectively, “can be a little bit hard to see.” The visual inaccessibility of these controls detracted from the perceived usability of P6’s experience.

**5.3.1.3 Several users called for more labels of anatomical landmarks.** According to P6, including more of these labels and making them responsive to user interaction — so as to expand when their corresponding anatomies are touched — would have been “interesting to have.” For example, “if, by tapping on a specific component [of the anatomy], you get to see [that] this is the spinal cord,” it is possible that P9 and other users would have felt the interface to be more responsive. Additionally, this example interaction suggests that users may find it helpful to have more informative textual elements that are conditionally visible. Allowing the user to expand certain pieces of information and hide them as needed may contribute to higher perceived usability of the application; a conditionally visible label, for instance, can be hidden again after being read so as to not unnecessarily clutter the interface and/or cognitively overload the user. It may offer more individualized learning experiences, wherein users can choose to reveal more information surrounding sources of confusion, and thus grant increased agency and freedom for self-directed learning.

**Aesthetic appeal (AE)**

Users were prompted to indicate their level of agreement with one statement measuring aesthetic appeal (AE): how visually attractive users felt the interface to be.

**5.3.1.4 Users expressed unanimous approval of the visual appearance of the application.** In response to the prompt, “The app is aesthetically appealing” (OFF.S2.A.Q3), 7/10 users responded ‘Strongly agree’ and the remaining 3/10 responded ‘Agree.’

Certain users explicitly cited this appearance as a source of delight, when responding
to the open-ended question, “Was there anything that delighted you while using the app? If so, what was it?” (OFF_S2.C.Q1). For some of these users, it was the aesthetics of the 2D UI that held particular appeal: P15 wrote that “the ‘sci-fi’ visuals made the procedure feel very modern,” suggesting that the visual design of the interface may engender certain audiences to think of the medical procedure as ‘state-of-the-art,’ up-to-date with contemporary medical advances, and perhaps more reliable as a result. Other users found the 3D visuals to be especially pleasing. P6 found “the color and texture of the visualizations” to be “really aesthetically engaging,” and P9 wrote that “the animation was very beautiful.”

We found no statistical significance in responses between Groups B and C, indicating that the absence or inclusion of AR features did not meaningfully affect users’ beliefs on AnatoView’s aesthetic appeal.

Endurability (EN)

Users were prompted to indicate their level of agreement with three statements measuring endurability (EN): how well-received the application overall was, and how willing users would be to use it in the future and/or recommend it to others.

5.3.1.5 AnatoView was unanimously well-received by users. In response to the prompt, “Overall, I had a positive experience with the app” (OFF_S2.A.Q5), 7/10 users responded ‘Strongly agree’ and the remaining 3/10 responded ‘Agree.’ In response to, “If I were a patient considering this treatment/procedure, I would want my physician to use this app to supplement their explanation” (OFF_S2.B.Q5), 9/10 users responded ‘Strongly agree’ and the remaining 1/10 responded ‘Agree.’ Lastly, in response to the open-ended question, “Would you recommend the app to people you know, if they were in a situation that called for using it?” (OFF_S2.C.Q3), users unanimously indicated that they would.

Five respondents, i.e. half of all responses, justified their recommendation by citing
the application’s 3D visualization features. P9, self-identifying as a “visual learner” and as “someone who has very little experience with medicine and medical procedures,” found the application to be “a great visualizer for the procedure.” Additionally, P9 attributed their ability to communicate with their physician, and actively participate in reinforcing their understanding, to this visualization: it allowed them to “think of questions that I might not have had if this procedure was explained to me verbally.” P11 compared the application’s 3D (and, in their case, AR-supported) visuals to traditional two-dimensional medical images; they wrote that “anyone who is interested in procedures like these would definitely want to look [at the application] instead of [looking at] a textbook.”

We found no statistical significance in responses between Groups B and C, indicating that the absence or inclusion of AR features did not meaningfully affect how well-received AnatoView was overall.

5.3.2 Relationship between augmented reality and engagement observed among Group C participants

To understand how augmented reality features specifically affected engagement, we compared self-reported engagement among the subset of users who encountered these features (Group C) against the subset of users who did not (Group B).

5.3.2.1 Users who did not use AnatoView’s AR visualization features were slightly more likely to feel very engaged than users who did — but this difference was not significant. As reported earlier, all five Group B users reported feeling maximally engaged while learning about the procedure, whereas there was a less unanimously maximal engagement among Group C users, wherein three users answered ‘Strongly agree’ and the remaining two answered ‘Agree.’ We employed the Mann-Whitney U Test and determined this difference to be statistically insignificant.
However, we are interested in addressing two possibilities. First, it is possible that certain users may be better-equipped for using certain application features, or undergoing certain learning interventions/modalities: an area of study that has been suggested by several literatures [20]. Second, it may be both feasible and beneficial for us to identify these proclivities and work to meet individual needs. Doing so may optimize learning outcomes for laypersons overall. This motivates us to hypothesize the following, with regards to the efficacy of AR-assisted learning mechanisms for users.

5.3.2.2 A lack of preexisting knowledge, familiarity, or experience with AR may discourage certain users from directly engaging with AnatoView’s AR features. For instance, P12 — an outlier among participants in terms of age (65 years) and non-student occupation (as a nurse) — reported the lowest familiarity with AR among all Group C participants, answering ‘Not familiar at all’ in response to our onboarding survey prompt, “How familiar are you with Augmented Reality (AR) technology?” (ON.S3.Q1). During the IC intervention, they were also the only participant among both experimental groups who did not elect to spend any time interacting with the application on their own.

5.3.2.3 It is possible that users with less digital literacy, e.g. familiarity with AR, may be most content with letting the accompanying physician handle the controls. Despite not engaging directly with AnatoView, P12 still responded positively to the application: answering either ‘Agree’ or ‘Strongly agree’ to all offboarding statements regarding engagement, enjoyment, perceived benefits of learning, etc., and describing the visualization features as “awesome.” This suggests that (a) seeing the physician control the application was fulfilling for the user, and (b) direct engagement with the application was not necessary for the user’s positive experience; there is, in fact, a chance that direct interactions would have detracted from that experience. Even among those who self-reported high digital literacy, there
was emphasis on the importance of seeing the physician model all interactions with the application first. Another user from Group C, P15 — who answered that they were ‘Very familiar’ with AR technology (ON_S3.Q1), ‘Extremely comfortable’ with using AR applications and devices (ON_S3.Q3), and ‘Strongly positive’ in their feelings toward AR technology (ON_S3.Q4) — wrote that they would “recommend the app to people [they] know, if [those people] were in a situation that called for using it” on the condition that “they were being guided through it by someone who knew or was actively using the controls” (OFF_S2.C.Q3).

5.3.2.4 It is evident, then, that users were comfortable placing trust in the physician to demonstrate use of the application and guide their initial exposure to its educational contents, and felt benefited by this guidance. Furthermore, although there is no conclusive evidence that Group C users were more likely to rely on physician guidance for engaging with the application compared to Group B users, it is still worth considering how we might infer user preferences for autonomous engagement/interaction through their digital literacy, and tailor educational supplements for IC accordingly.

5.3.3 Relationships between engagement and other outcomes

We discovered the following correlations between engagement and other measured outcomes.

5.3.3.1 Feeling engaged during the IC intervention, while learning about the medical procedure, meaningfully encouraged participants to communicate more with physicians and obtain a better understanding of the procedure. There was a strong and statistically significant positive correlation between participants’ self-reported engagement and the frequency with which they asked procedure-related questions (R = 0.54; p = 0.04).
5.3.3.2 Feeling engaged during the IC intervention, while learning about the medical procedure, greatly contributed to participants’ overall medical comprehension. There was a strong positive correlation between participants’ self-reported feelings of engagement and participants’ improvement in comprehension score between T1 and T2, which we found to be statistically significant (R = 0.54; p = 0.04). Furthermore, engagement was a strong predictor for improved comprehension ($\beta = 0.96$).

We conclude overall that our interactive multimedia educational intervention helped participants feel more engaged in their learning, playing an active role in their own medical comprehension — which, as a result, significantly benefited from greater engagement.
6 Limitations

Our study is limited in its amount of participants (n = 15) and the homogeneous demographics therein. Due to our recruitment methods, the vast majority (14/15) of our participants were ages 18 through 24 years old and pursuing post-secondary education through a bachelor’s, master’s, or doctorate program. We recruited only one participant who was an outlier in age (65 years); this participant, P12, was also an outlier in two other regards: reporting a minimal digital literacy (i.e. familiarity with AR), and opting to not independently interact with our experimental intervention, AnatoView. Observational data collected via this participant suggests a relationship between a lack of familiarity with AR and a disinclination to directly use it (a preference, instead, for another, i.e. an accompanying physician, to take control). However, due to our limited sample size, there are not enough users to conclusively determine the existence of this relationship. Moreover, although we found a strong negative correlation between age and self-reported familiarity with AR, the homogeneity in users’ age overall dampens the statistical significance and conclusiveness of this finding.

Additionally, although our cervical medial branch block comprehension assessment was written by a physician with experience in the procedure — then fact-checked to determine accuracy in content — the questions were still not written by an education expert. Therefore, there is no guarantee that the questions were designed (i.e. phrased) to conduct the fairest possible evaluation of participants’ knowledge; if certain questions were phrased confusingly, for instance, then the comprehension assessment can not be a truly objective measure of how well-informed a participant is.

Finally, our proposed informed consent intervention does not address all inadequacies in the informed consent process. To begin, physicians receive little training on how to conduct informed consent discussions [28]. Although AnatoView may help the physician more reliably explain a procedure — by using AnatoView’s walkthrough
feature as a script for delivering a spoken explanation — it cannot replace the essential training that physicians should have for resolving patients’ questions. Moreover, the use of a patient’s signature to obtain informed consent is dangerous. We found that subjective knowledge had no bearing on objective knowledge among laypersons, and concluded that patients are not reliable reporters or judges of how well-informed they are on a procedure. Therefore, having patients sign off on a document after they believe they are sufficiently well-informed is not synonymous with that patient providing their objectively informed consent. Our intervention focuses on improving patient/layperson comprehension to increase the likelihood of patients being able to provide informed consent; however, it does not resolve the equally dangerous inadequacy in how informed consent is obtained and documented.

This final inadequacy we are unable to address is something we were cognizant of while designing our study. We intentionally controlled for English proficiency among our participants so as to control for what would otherwise be a confounding variable, according to several peer studies on informed consent, allowing us to strictly measure the effectiveness of using AnatoView against not using AnatoView in a controlled study environment. However, the reason why English proficiency ‘is a confound,’ so to speak, is because non-English speakers are at highest risk for poor comprehension in informed consent. This is the demographic that should arguably be prioritized in efforts to improve the informed consent process. Therefore, controlling for (the absence of) a vulnerable population means that we have not yet proven AnatoView’s effectiveness on improving informed consent for those it presently harms most.
7 Future work

Future implementations of this study should seek to resolve these aforementioned limitations in its initial design. More participants overall, who belong to more heterogeneous demographics (i.e. age), should be recruited to power the study toward more significant, conclusive results. Correlations and other relationships between these demographics and measured outcomes (medical comprehension, communicativity, engagement) should be examined. Moreover, the comprehension assessment should be either written or vetted by an education expert to ensure fair, accurate evaluation of layperson comprehension regarding the medical procedure.

To improve AnatoView to more robustly address other inadequacies outside of poor patient instruction and comprehension — such as physicians’ lack of training — in the traditional informed consent process, we can consider designing tests to evaluate how physicians respond to using AnatoView. In conjunction, we can reframe our research question to measure how effectively physicians use AnatoView as an instructional tool, decentering how effectively patients respond to AnatoView as a learning supplement. This would allow us to consider AnatoView as a solution for providing physicians with more standardized protocols for obtaining informed consent. It is also possible to combine these questions into one study: designing onboarding and offboarding surveys as well as other data collection methods to simultaneously evaluate how (a) patients benefit from learning via AnatoView, and (b) physicians benefit from instructing via AnatoView.

Designing AnatoView to accommodate both physicians and patients would be valuable, given that the current proposed integration of AnatoView into existing clinical workflows entails physician use of the application (as a precursor to patient/layperson use). We trained the physicians who assisted with this study on how to use AnatoView — providing them with a script of interactions to ensure standardization across users’ instruction. However, in a practical scenario outside of an academic study, it would
be impractical to train all physicians to use the application. For instance, collecting
and improving from feedback on how usable or intuitive physicians find the interface
may help us build an application that is easier for both parties of the informed consent
process to use. If physicians become more adept at teaching patients/laypersons, this
would fulfill our objective of improved patient learning outcomes.

The study could also be reproduced on other medical procedures to determine a con-
sistency (or lack thereof) in measured outcomes — medical comprehension, commu-
nicativity, and engagement — for other use cases. This would entail using another one
of AnatoView’s available educational modules, which currently include other chronic
pain treatment procedures such as the transforaminal lumbar epidural steroid injec-
tion (TFESI), in our trial. If we observe similar trends in outcomes among different
procedures between users and non-users, we can more conclusively determine the
benefits of AnatoView on these outcomes.

Our first implementation of this study also raised several promising areas of related
research that we could devote future iterations of this study to understanding. One
research question could focus on predicting learning modalities that would be ben-
eficial for certain users to ensure more optimal learning outcomes overall. From our
results, we observed that users who reported low familiarity with AR benefited less
from learning with AR. This motivates a future area of study in whether learning
modalities — whether the user’s education would benefit from augmented reality
support, for example — can be accurately, fairly predicted from users’ background,
self-reported preferences, self-efficacy evaluations, and so forth. With this under-
standing, we could then examine how to tailor educational supplements for patients
accordingly. Peer studies on informed consent interventions have also identified this
to be a question that is simultaneously promising yet under-researched [20].

Finally, it would be worthwhile to evaluate the effects of AnatoView on patients’
emotions. Laypersons, especially those who had previously received medical proce-
dures wherein they felt frustrated and uninformed (i.e. P10), responded emotionally
to using *AnatoView*, describing it as “comforting,” “relieving,” or helpful for feeling less “lost.” Through established measures such as the State-Trait Anxiety Inventory (STAI), we can more closely examine the benefits of *AnatoView* on patients’ subjective experiences. This would require us to recruit not just laypersons, but actual patients — specifically those considering the medical procedure we designate as our use case. Patient anxiety is highly circumstantial: layperson anxiety — experienced while learning about a procedure with no material relevance to the learner — cannot be substituted for patient anxiety, inextricable from patients’ material reality.
Bibliography


A Comprehension assessment

Below is a reproduction of the 10-question multiple-choice comprehension assessment on the use-case medical procedure, the cervical medial branch block (CMBB), that was administered to all participants at timepoints T1/pre-intervention and T2/post-intervention. The assessment was written by a licensed physician and pain specialist assisting with the study, and fact-checked against multiple sources for accuracy. In this reproduction, the correct answer to each question is bolded.

Instructions:

Below are ten (10) multiple-choice questions about the cervical medial branch block (CMBB) technique. For each question, please circle the correct answer to the best of your ability.

You will be given 5 minutes to complete the assessment. You do not have to use all 5 minutes of your time. If you complete the assessment early, please let the physician know.

(Questions begin on following page.)
1. What is the purpose of performing the cervical medial branch block (CMBB)?

(a) To diagnose and treat pain originating from the facet joints
(b) To diagnose and treat pain originating from the spinal cord
(c) To diagnose and treat pain originating from the muscles
(d) To diagnose and treat pain originating from the nerves

2. What is the primary diagnostic purpose of CMBBs?

(a) To identify the source of neck pain
(b) To evaluate spinal cord compression
(c) To determine muscle weakness
(d) To diagnose nerve damage

3. What type of medication is typically injected during the CMBB?

(a) Muscle relaxers
(b) Steroids
(c) Local anesthetics
(d) Antibiotics

4. What is the potential benefit of CMBBs for patients?

(a) Temporary relief of pain from the target area
(b) Long-term (≥ 1 month) relief of pain from the target area
(c) Enhanced flexibility and muscle strength around the target area
(d) Increased blood flow to the target area

5. If the CMBB trial is successful (i.e. reduces the patient’s pain in the target area), what is the typical next step for treatment?

(a) The CMBB is repeated indefinitely as needed to provide pain relief
(b) The medial branch nerves are destroyed using a needle with a heated tip called radiofrequency ablation (RFA)

(c) Steroids are injected into the facet joints to decrease pain and inflammation

(d) The patient is referred to a spine surgeon, as surgery is likely needed

6. Following a CMBB, what should a patient do with regards to the area that was treated by the CMBB?

(a) Monitor and record the pain level in that area every hour, for the next 4-6 hours

(b) Avoid moving that area of the body as much as possible

(c) Submerge the area by taking a bath or swimming

(d) Apply a warm compress to the area

7. The CMBB involves the placement of multiple needles into the lower back: true or false?

(a) True

(b) False

8. The CMBB blocks pain signals from the target area by injecting the medication from Question 3 into the cervical spine joints (AKA facet joints): true or false?

(a) True

(b) False

9. The needles used in the CMBB are inserted:

(a) Into the joints of the spine

(b) Along the side of the spine

(c) Into the spinal cord
(d) Into the epidural space of the spine

10. **The facet joints are supplied by nerves from:**

(a) The vertebrae above the joint

(b) The vertebrae below the joint

(c) **The vertebrae above and below the joint**

(d) The innervation to these joints is variable
B Onboarding survey

What follows is a reproduction of the onboarding survey administered to participants prior to the T1/pre-intervention comprehension assessment. Note that the third page, prompting respondents to indicate their background with augmented reality (AR) technology, was exclusively administered to Group C participants.
Name

Age

Gender

Please select your level of education. If you are currently a student, mark the education level you are currently pursuing. If you are not currently a student, mark the most recent education level you completed.

- High school
- Bachelor’s degree
- Master’s degree
- Doctorate or PhD
- Professional degree (e.g. MD, JD)
- Other (please specify)
The following section contains a series of statements regarding visual learning. Please read each statement and indicate how much you agree with it.

<table>
<thead>
<tr>
<th>Statement</th>
<th>Strongly disagree</th>
<th>Disagree</th>
<th>Neutral</th>
<th>Agree</th>
<th>Strongly agree</th>
</tr>
</thead>
<tbody>
<tr>
<td>I consider myself a visual learner.</td>
<td>○</td>
<td>○</td>
<td>○</td>
<td>○</td>
<td>○</td>
</tr>
<tr>
<td>I find visual representations of information to be engaging.</td>
<td>○</td>
<td>○</td>
<td>○</td>
<td>○</td>
<td>○</td>
</tr>
<tr>
<td>The use of visual aids enhances my understanding of complex concepts.</td>
<td>○</td>
<td>○</td>
<td>○</td>
<td>○</td>
<td>○</td>
</tr>
<tr>
<td>I retain more information when visual aids are used to supplement text-based materials, compared to when they are not.</td>
<td>○</td>
<td>○</td>
<td>○</td>
<td>○</td>
<td>○</td>
</tr>
<tr>
<td>I prefer visual learning to other learning modalities (e.g. auditory, kinaesthetic).</td>
<td>○</td>
<td>○</td>
<td>○</td>
<td>○</td>
<td>○</td>
</tr>
</tbody>
</table>

The following section contains a series of tasks. For each task, please rate how helpful visual learning is for you accomplishing this task.

<table>
<thead>
<tr>
<th>Task</th>
<th>Visual learning is not helpful</th>
<th>Visual learning is slightly helpful</th>
<th>Visual learning is moderately helpful</th>
<th>Visual learning is very helpful</th>
<th>Visual learning is extremely helpful</th>
</tr>
</thead>
<tbody>
<tr>
<td>Understanding complex information</td>
<td>○</td>
<td>○</td>
<td>○</td>
<td>○</td>
<td>○</td>
</tr>
<tr>
<td>Retaining information for longer periods of time</td>
<td>○</td>
<td>○</td>
<td>○</td>
<td>○</td>
<td>○</td>
</tr>
<tr>
<td>Solving problems via critical thinking</td>
<td>○</td>
<td>○</td>
<td>○</td>
<td>○</td>
<td>○</td>
</tr>
<tr>
<td>Communicating complex information to others</td>
<td>○</td>
<td>○</td>
<td>○</td>
<td>○</td>
<td>○</td>
</tr>
</tbody>
</table>

Please rate your confidence in performing the following spatial reasoning task.

<table>
<thead>
<tr>
<th>Task</th>
<th>Not confident at all</th>
<th>Slightly confident</th>
<th>Moderately confident</th>
<th>Very confident</th>
<th>Extremely confident</th>
</tr>
</thead>
<tbody>
<tr>
<td>If I see a 2D image (i.e. a photo) of an object, I can mentally visualize that object in 3D space.</td>
<td>○</td>
<td>○</td>
<td>○</td>
<td>○</td>
<td>○</td>
</tr>
</tbody>
</table>
How familiar are you with Augmented Reality (AR) technology?

- Not familiar at all
- Slightly familiar
- Moderately familiar
- Very familiar
- Extremely familiar

How often do you use Augmented Reality (AR) technology, such as AR applications or devices, in your personal or professional life?

- Never use it
- Rarely use it
- Occasionally use it
- Frequently use it
- Always use it

How comfortable are you with using Augmented Reality (AR) applications and devices?

- Not comfortable at all
- Slightly comfortable
- Moderately comfortable
- Very comfortable
- Extremely comfortable

How would you describe your feelings toward Augmented Reality (AR) technology?

- Strongly negative
- Somewhat negative
- Neutral
- Somewhat positive
- Strongly positive

Would you like to elaborate on any of your answers to the questions above? If so, please do so here:

[Text box for additional comments]
C Offboarding survey

What follows is a reproduction of the offboarding survey administered to participants after the T2/post-intervention comprehension assessment. Note that the second page, prompting respondents to reflect on their experience with using and learning through the AnatoView application, was exclusively administered to Group B and C participants. Additionally, the question, "Seeing the treatment/procedure visualized in Augmented Reality (AR) space helped me understand it," is rephrased to replace "Augmented Reality (AR)" with "three-dimensional (3D)" for Group B users/participants.
The following section contains a series of statements regarding the treatment/procedure you learned about today (the cervical medial branch block, or CMBB). Please read each statement and indicate how much you agree with it.

<table>
<thead>
<tr>
<th>Statement</th>
<th>Strongly disagree</th>
<th>Disagree</th>
<th>Neutral</th>
<th>Agree</th>
<th>Strongly agree</th>
</tr>
</thead>
<tbody>
<tr>
<td>The purpose of the treatment/procedure was clear to me.</td>
<td>○</td>
<td>○</td>
<td>○</td>
<td>○</td>
<td>○</td>
</tr>
<tr>
<td>The information about the treatment/procedure was provided in a format that was easy to understand.</td>
<td>○</td>
<td>○</td>
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<td>○</td>
<td>○</td>
</tr>
<tr>
<td>I was engaged while learning about the treatment/procedure.</td>
<td>○</td>
<td>○</td>
<td>○</td>
<td>○</td>
<td>○</td>
</tr>
<tr>
<td>I felt better prepared for the 10-question comprehension assessment after learning about the treatment/procedure vs. before.</td>
<td>○</td>
<td>○</td>
<td>○</td>
<td>○</td>
<td>○</td>
</tr>
<tr>
<td>Overall, I feel well-informed about the treatment/procedure.</td>
<td>○</td>
<td>○</td>
<td>○</td>
<td>○</td>
<td>○</td>
</tr>
<tr>
<td>If I were a chronic pain patient considering the treatment/procedure as an option for pain relief, I would consent to receiving it.</td>
<td>○</td>
<td>○</td>
<td>○</td>
<td>○</td>
<td>○</td>
</tr>
</tbody>
</table>

Please include any additional comments you'd like to share with us about the session.

[Comment field]

Next page ⬤
The following section contains a series of statements regarding your experience with the app you used today. Please read each statement and indicate how much you agree with it.

<table>
<thead>
<tr>
<th>Statement</th>
<th>Strongly disagree</th>
<th>Disagree</th>
<th>Neutral</th>
<th>Agree</th>
<th>Strongly agree</th>
</tr>
</thead>
<tbody>
<tr>
<td>I felt engaged while using the app.</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>I found using the app to be straightforward and easy to understand.</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>The app is aesthetically appealing.</td>
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<tr>
<td>I enjoyed physically interacting with the device (iPad) the app was displayed on.</td>
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<tr>
<td>Overall, I had a positive experience with the app.</td>
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</tbody>
</table>

The following section contains a series of statements on your experience with the app you used, in relation to your understanding of the treatment/procedure you learned about. Please read each statement and indicate how much you agree with it.

<table>
<thead>
<tr>
<th>Statement</th>
<th>Strongly disagree</th>
<th>Disagree</th>
<th>Neutral</th>
<th>Agree</th>
<th>Strongly agree</th>
</tr>
</thead>
<tbody>
<tr>
<td>I enjoyed using the Augmented Reality (AR) features of the app.</td>
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<tr>
<td>Seeing the treatment/procedure visualized in Augmented Reality (AR) space helped me understand it.</td>
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<tr>
<td>I had an easy time connecting what I saw in the app to what I heard the physician explain to me.</td>
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<tr>
<td>Having the app as a supplement to the physician's explanation was helpful for my understanding.</td>
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<tr>
<td>If I were a patient considering this treatment/procedure, I would want my physician to use this app to supplement their explanation.</td>
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</tbody>
</table>

Was there anything that delighted you while using the app? If so, what was it?

Did you encounter any problems while using the app, and/or was there anything you found confusing about the app?

Would you recommend the app to people you know, if they were in a situation that called for using it?