# The Magical Cabinet of Curiosities: Exhibiting EPFL's Scientific Instruments Collection

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## I. Introduction

This design document outlines our proposal for a digital exhibition of the UNIL-EPFL Collection of Scientific Instruments (CSI) [1]. Largely the result of two centuries' worth of physics teaching and research at UNIL and the Old Academy of Lausanne, the CSI is, simply put, a set of historical objects related to scientific endeavours.

In addition to benefiting historians of science, the CSI is intended to be a source of education and wonder for the public. However, most of the CSI's 1000+ instruments are only viewable by the public in the form of photos and accompanying French-language metadata on EPFL's website. Additionally, those approximately 200 instruments on physical display as of June 2023 are housed in geographically disperse display cases throughout EPFL and UNIL's campuses, often with little accompanying information and little opportunity for user interaction. Our proposal unites all CSI objects in one place, illustrates linkages between them according to their metadata, and most importantly, allows the public to scrutinize, take apart, and put in-use instruments in a manner that is both conducive to learning and only possible with a virtual display. Rather than view this proposal as a recontextualization of the CSI, we consider it a return to the learning environment many of its objects were originally intended for, and believe the novel linkages we establish would help the public to navigate and make sense of the vast collection - while preserving the sensation of peculiar, joyful discovery present in historical modes of scientific display such as cabinets of curiosity (see Figure 1).

We thank Professor Jérôme Baudry and Dr. Ion-Gabriel Mihailescu for providing access to the instruments and metadata involved in this project. We would welcome the opportunity to implement those ideas from this proposal that they deem feasible.

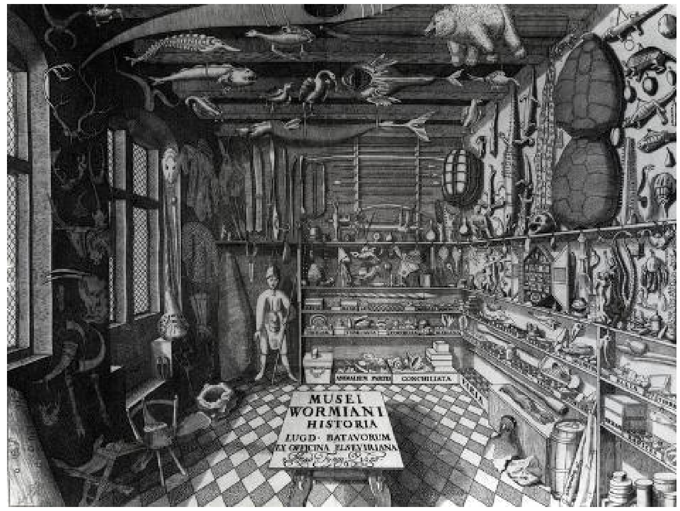


Fig. 1: "Musei Wormiani Historia": Ole Worm's cabinet of curiosities (from Wellcome Collection [2]).

## II. Research & Development

Our Magical Cabinet of Curiosities design concept is the result of two weeks of initial research and four weeks of partial implementation alongside further research.

The immediate questions we asked ourselves upon commencing this project were the following: what do we wish to show with each instrument's 3D model that is beyond what can be shown in reality? How can we give users the functionality to learn from and play with each virtual instrument without imposing a learning curve? Which installation device would balance the functionality we require with the dimensions of navigation we desire? The answers to these questions stemmed from our own thoughts about what we wish we could do with the instruments and by researching the types of installations at our disposal.

Concerning ourselves only with the initial 35 instruments provided by Professor Jérôme Baudry and Dr. Ion-Gabriel Mihailescu in these early stages, we first conceived of the branches at the top right of the Mind Map shown in Figure 2: display of the 3D models and their associated historical content.

Our interest in the broader CSI grew as we discovered the wealth of metadata available on the CSI's website. As we familiarized ourselves with the data, we came to believe users would benefit from a system that relates the instruments to one another - a system that does not currently exist except through categorizations related to scientific field. Soon the scope of our project had grown to all 1000+ instruments in the CSI (if not as instruments to be interacted with then as instruments to be visualized), and we began to suspect a clustering system would need to be implemented along with the necessary data collection and processing.

We then conceived of a few possible installations: rotation-based navigation of a few dozen instruments in the Object Navigator, horizontal and vertical navigation of all instruments in the Linear Navigator, and controller-based navigation of instrument clusters in the Cupola. The first would sacrifice scope, the second, clustering and navigability, and the third, navigability and ease of comprehension. Ultimately, we decided to incorporate our clustering focus from the Cupola concept into the Object Navigator concept, building out the latter's functionality to accommodate the entire CSI. Items in the CSI possess a high degree of specialization and associated information; with over one thousand available, we wanted to lean on the simplicity of the Object Navigator's rotation and an added pair of buttons alone to streamline user selection and navigation.

From this decision stemmed the incorporation of our "Cabinet of Curiosities" theme. Introduced to us alongside the initial data, the term Cabinet of Curiosities refers to a historical mode of scientific display in which collectors would organize artifacts in rooms for public viewing, at times in an apparently arbitrary manner [3]. By concealing the math of our clustering and placing a level of trust in the user, we saw a path toward presenting the entire CSI with neither obvious subcategorization nor navigational barriers - just as the Curio Cabinets did with their collections. The anatomy lecture hall virtual environment we subsequently selected was in keeping with the theme of scientific display.

The aforementioned Mind Map incorporates all of these concepts into one chart: physical installation, display of the 3D models, the instruments' information, the instruments' relationships, and the virtual environment, and historical theme. Also included are some details of later implementation - technical tools, user experience, and future expansion. After two weeks of research, we had settled on an educational, immersive, and virtual experience showcasing the CSI through instruments' linkages and details alike, achieving robust interactivity with intuitive navigation. We present our precise concept in the next section.

## III. Concept

We propose to allow users to explore the relationships, functions, and details of all (or nearly all) 1,034 scientific instruments with a layered experience entirely contained in the Object Navigator (see Figure 3 for a photo of Object Navigator).

There is an inherent tension in making museum objects of scientific instruments: suddenly, that which we believe belongs in our hands is locked out of reach. The primary reason we see the need for this exhibit, then, is simple: this digital display gives users exactly what they crave. Of course, we also design an experience such that users will be encouraged to think critically about the CSI's instruments in ways they haven't before. There is, after all, an untapped educational power to this collection.

The value proposition of this experience is its novel approach to organizing instruments at scale such that users can navigate throughout the collection without information overload or lack of stimulation. Beyond this organizational structure, intuitive user power in selection and interaction with instruments never before depicted in the virtual realm will engage user interest.

Our vision is for the core experience to be an educational and fun tool with which users can discover intricacies without risking the integrity of the instruments themselves. It will provide the interactivity users wish they could have with real historic objects and deliver all the information they might think to seek out - along with network information they might not even know they want. Best of all, it will accomplish all of this with no more than a double-sided 3D screen, a handrail for rotation, and two buttons. Users will freely navigate a series of four layers - three layers composed of groups of 3D-modeled instruments and one layer composed of a selected instrument's 3D model - to explore instruments of their choosing.

It is our hope that users will take away the following understandings:

1) *The CSI is an educational goldmine.* Multi-layer interface design and comprehensive instrument explanations will present the breadth and depth of the CSI in a digestible way. It will be evidently beneficial to students, teachers, and those with an interest in science, and intimidation before the CSI will dissipate thanks to user agency.
2) *Science is better as a participant.* The Magical Cabinet of Curiosity squeezes interactivity out of its handrail and two buttons. Seeing this interactivity translate into full-on manipulation of instruments should delight users, increase their engagement, and allow them to see the potential of scientific instruments in a new light.
3) *Historical science is composed of an ensemble cast.* The intelligent use of color, layout, and other design elements on specific layers will communicate the ways instruments are linked, thereby enabling users to grasp how cohesive certain subsets of the CSI actually are.

## IV. Data Analysis

### A. Motivation

To explain our data and data analysis, we must first introduce the organizational structure we propose for the CSI inside the Object Navigator.

One might imagine the structure our users navigate as a funnel. At the top of this funnel - what we call the "Top Layer" - users select a category representing the general scientific field they wish to explore (Optical instruments, for example). In the second layer, or "Aggregate Layer", the user will encounter a set of clusters which, between them, house every single instrument within the category selected in the Top Layer. The user then proceeds to select a cluster and moves into the "Cluster Layer" before finally selecting an individual instrument and exploring it in the "Instrument Layer". A simple schematic of this organizational structure is shown in Figure 4. We do not yet address the question of how users navigate between and select entities because it is irrelevant to the data processing pipeline.

In all layers except the Instrument Layer, we only allow a maximum of 16 entities (categories in the Top Layer, clusters

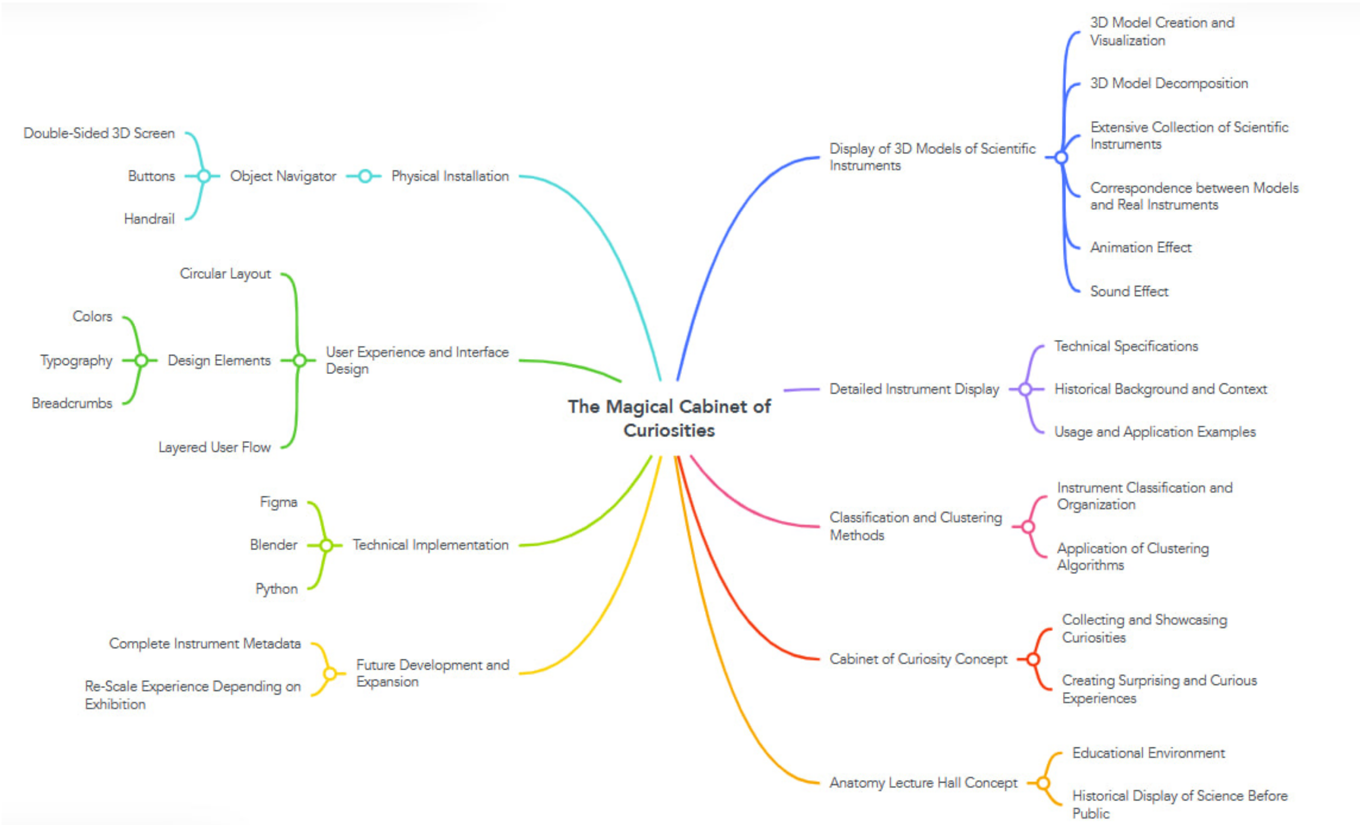


Fig. 2: Mind Map for the Magical Cabinet of Curiosities

in the Aggregate Layer, and instruments in the Cluster Layer) to appear at once. 22.5° out of the Object Navigator's 360°, then, are reserved for any single entity. This rule requires all instrument categories to house $16^2$ instruments or less given the structure we propose (if a category housed more than $16^2$ instruments, then one of the 16 clusters in the Aggregate Layer would have more than 16 instruments - leading to crowding on the Cluster Layer).

Why do we propose this series of layers? We believe displaying the entire CSI with one rotation around the Object Navigator would "cram" the virtual real estate and overwhelm the user. A series of layers, if designed properly, enables the user to navigate throughout the CSI and explore individual objects in a manner that is intuitive, educational, and interest sustaining. Nonetheless, we discuss alternatives to this 4-layer system in our Conclusion.

### B. Analysis

Our dataset is the list of all instruments in the CSI along with associated metadata maintained by the CSI's curators. Given the discussion above, one requirement for our proposed structure is a set of 16 (or less) categories that reflect a natural grouping according to scientific field. On the CSI's website, there are 20 categories organized according to scientific field; Table I presents the name of each category as well as the number of instruments it contains.

It is apparent that some regrouping is required to yield 16 categories maximum. One possible regrouping is as follows: first, because there are 423 instruments related to electricity & magnetism, this category can be split between instruments used for measurement and those not used for measurement, with each subgroup amounting to less than $16^2$ instruments total. Though all other categories amount to less than $16^2$ instruments as well, the now 21 categories must be reduced to a set of 16 through aggregation or removal. We propose aggregating where there is some overlap in scientific domain - Atomic Physics and Radioactivity & Nuclear Physics, for example - or in-use appearance - Luminescence & Phosphorescence and Miscellaneous & Fun Physics, for example - whenever possible. Provided the two unclassified instruments are removed, just four category aggregations need to occur to arrive at 16 total. Table II presents the modifications listed above along with two further groupings and the removal of 2 unclassified objects to create a set of categories suitable for our installation. Note that this is just one possible categorization procedure out of many. It is interesting to note that given any category can contain up to $16^2$ instruments, our installation can fit the entire CSI within five Top Layer categories. In an extreme case, then, curators might fully emulate the arbitrary organization of historical curio cabinets by shuffling the entire collection between 4-5 unlabeled categories at random and allowing the clustering pipeline described in the next subsection

Fig. 3: Object Navigator

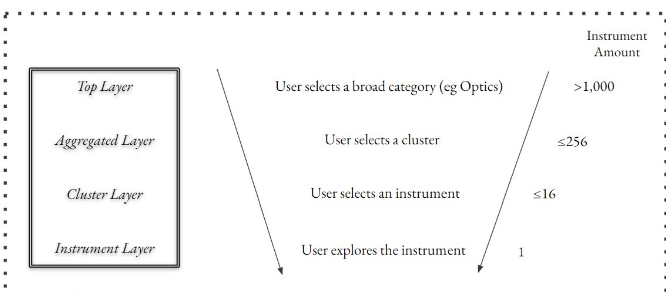


Fig. 4: Users explore the CSI by navigating a "funnel-like" series of layers.

| Category | # Instruments |
|---|---|
| 1. Electricité & Magnétisme | 423 |
| 2. Optique | 238 |
| 3. Poids & Mesures | 61 |
| 4. Radioactivité et Physique Nucléaire | 58 |
| 5. Chaleur | 39 |
| 6. Mathématiques | 28 |
| 7. Chimie, Chimie Physique et Électrochimie | 27 |
| 8. Documents | 27 |
| 9. Acoustique | 24 |
| 10. Hydrostatisque et Hydraulique | 20 |
| 11. Rayons X | 19 |
| 12. Physique de l'Atmosphère et de la Terre | 18 |
| 13. Mécanique des Corps Solides | 9 |
| 14. Equipement de Laboratoire | 9 |
| 15. Astronomie, Cosmographie & Géographie | 9 |
| 16. Pneumatique | 8 |
| 17. Physique Atomique et Moléculaire | 5 |
| 18. Luminescence, Phosphoresence | 5 |
| 19. Divers & Physique Amusante | 4 |
| 20. A Classer | 2 |

TABLE I: Collection of Scientific Instruments - Website Categorizations.

| Category | # Instruments |
|---|---|
| 1. Electricité & Magnétisme - Other | 240 |
| 2. Electricité & Magnétisme - Liés à la Mesure | 183 |
| 3. Optique | 238 |
| **4. Mathématiques,<br>Poids & Mesures** | **89** |
| **5. Physique Atomique et Moléculaire,<br>Radioactivité et Physique Nucléaire** | **63** |
| 6. Chaleur | 39 |
| 7. Chimie, Chimie Physique et Électrochimie | 27 |
| 8. Documents | 27 |
| 9. Acoustique | 24 |
| 10. Hydrostatisque et Hydraulique | 20 |
| 11. Rayons X | 19 |
| 12. Physique de l'Atmosphère et de la Terre | 18 |
| **13. Pneumatique,<br>Mécanique des Corps Solides** | **17** |
| 14. Equipement de Laboratoire | 9 |
| 15. Astronomie, Cosmographie & Géographie | 9 |
| **16. Luminescence, Phosphoresence,<br>Divers & Physique Amusante** | **9** |
| A Classer | 2 |

TABLE II: Collection of Scientific Instruments - Installation Categorizations. Red = removal, black = combination, blue = split.

to make sense of them in the Aggregate and Cluster Layers.

The other major requirement for effecting our proposed structure is the presence of metadata that can cluster subsets of the CSI in sensible ways. To determine whether this is the case, we inspected the metadata file provided by Professor Baudry to uncover all potentially available data for a given instrument. The metadata file included instrument name, unique instrument ID, partner instrument(s), category, accessories, date of entry into metadata file, start and end approximations for years of use, manufacturer, acquisition date, dimensions, location, state of conservation, importance to collection, inscription description, method of acquisition, number of copies in the CSI, country of origin, proprietor, use case, monetary value, and description on website.

To prepare for clustering, we filtered this set to those variables for which (1) data was missing for less than 50 instruments (here, missing means un-coded; in our opinion, values coded as "Unknown" still reflect something about curators' knowledge of the instruments), (2) data related to the instrument as an object rather than as an item in the

CSI (the date the instrument was entered into the collection, for example, was not retained), (3) a standard user would be able to comprehend its meaning, and (4) possible values were relatively limited (unless the variable in question was numeric, in which case any range was suitable). This filtering process left us with seven variables: approximate start to years of use, approximate end to years of use, manufacturer, state of conservation, country of origin, use case (whether it was used for teaching or research, for example), and dimensions. Though other variables were retained to display links between objects after clustering, it is only these seven variables which were incorporated into our clustering pipeline as described in the next section. We notably exclude subcategories related to scientific field from our clustering variables so that beyond the Top Layer, instruments are grouped together in less anticipated ways, imitating the experience of those visiting a historical curio cabinet.

## V. Data Augmentation

Our chief modes of augmentation involved updating and manipulating a 3D model of a Holmes stereoscope housed in the CSI as well as applying a clustering algorithm to all instruments in the CSI (with most refinement dedicated to the category of Optical instruments). This project relied on the eM+ laboratory's effort in scanning the aforementioned Holmes stereoscope and providing its 3D model.

### A. Metadata Augmentations

Preparing the data for clustering required several manual augmentations. For a given instrument, we first replace missing or unknown categorical variables within our seven cluster variables with the instrument's unique identification ID; this allows the instrument to be included in the clustering pipeline while ensuring its distances to other instruments are not made artificially low due to intersections in the set of missing variables. We then standardize manufacturer names and states of conservation across all instruments. The final and most intensive aspect of clustering preparations involves the dimensions variable. Dimensions data for each of the 238 instruments in the optical category is manually converted into width, length, height, and diameter, depending on object shape. Those instruments for which dimensions metadata is unclear or absent are observed on the CSI website and mapped to the dimensions of similar objects. Instruments with the A4 shape are assigned dimensions corresponding to a thick A4-shaped folder. After these modifications, we calculate volume for Optical instruments and drop individual dimension variables. This process is necessary as numerical data must be present for an instrument to enter our clustering pipeline.

We moved to automated augmentations after manual augmentations, first calculating pairwise distances between instruments based on start- and end-date of usage, manufacturer name, state of conservation, country of origin, use case, and volume. Our distance metric was Gower's distance, which can accommodate a mix of numerical and categorical data [4]. Though we propose that each variable receives equal weight, Gower's distance can also accommodate weighting differences should the CSI curators feel the clustering should give preference to certain variables. Pairwise distances are only calculated between instruments of the same category (that is, for all instruments in view in the Aggregate Layer).

For a given category with N instruments, our pairwise distances build N-dimensional distance vector representations of each instrument (one distance to each instrument, including itself). To reduce these N-dimension vector representations, we apply the UMAP dimension reduction algorithm [5], yielding two-dimensional representations for each category. See Figure 5 for a two-dimensional representation of the 238 instruments in the Optical category.

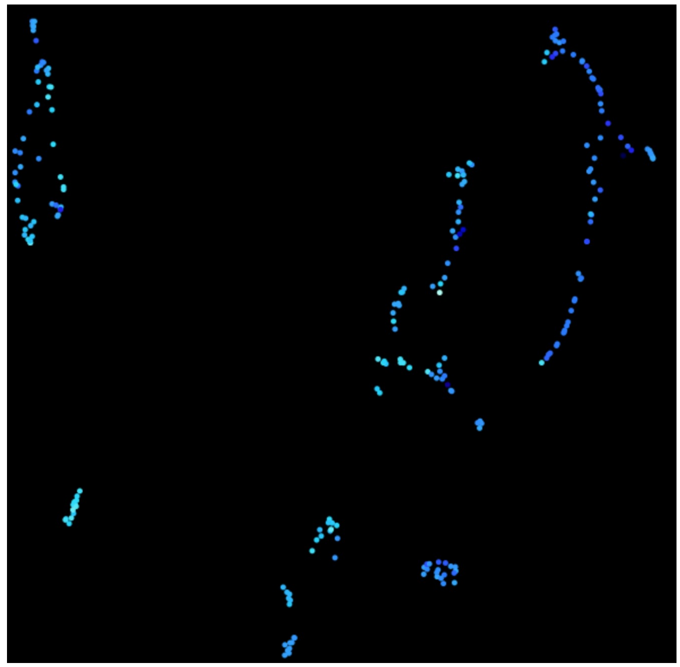

Fig. 5: UMAP applied to pairwise Gower's distance between instruments in the Optical category.

Finally, to arrive at the clusters presented in the Aggregate Layer, we apply K-means clustering to the two-dimension output for each category, setting the number of clusters $K = \lceil N/16 \rceil$.

Intra-cluster linkages between instruments are displayed in the Aggregate, Cluster, and Instrument Layers, and are determined **after** our clustering pipeline determines groups based on date of use, country of origin, use case, state of conservation, manufacturer, and size. To uncover linkages, we simply find intra-cluster alignment for any metadata variable mentioned in the Analysis section above (apart from date of entry into metadata file and website description) as well as subcategory (eg Spectacles & Telescopes within the Optics category). Note that clustering variables themselves are incorporated into the linkages we display. Numeric variables like date of operation are slotted into global bins such as "late-19th century" to make alignment related to these variables practically possible. Non-numeric variables that take on more diverse values can be converted to a binary variable to make alignment possible. For example, a variable describing inscriptions is converted to a binary variable indicating whether an inscription is present on the instrument or not. An example cluster from Figure 5 along with a subset of corresponding linkages are displayed in Appendix Table IV.

### *B. 3D Model Augmentations*

Transforming the scanned raw models into ones suitable for virtual exhibition includes several necessary steps. Assuming the raw scanned models are high-poly single meshes, these should at least include: *Mesh separation and cleaning*, *Re-topology*, *Texturing* and *Animating*. Additionally, because we want instrument-specific information to appear alongside instruments' individual components, the last step we require is *Information binding*. Figure 6 displays a 3D model we readied for virtual display with the steps listed above and described below.

*1) Mesh separation and cleaning:* this involves fixing errors in the model (for instance: floating vertices, non-manifold faces, and holes) and separating the composed model into different functional parts. There exist numerous apps that assist with this process; Table III lists suggested Blender edit-mode operations for performing mesh clean-up alongside a brief description of each.

| Operation in Edit mode | Description |
|---|---|
| Mesh → Clean Up → Delete Loose | Delete loose vertices, edges, or faces. |
| Mesh → Clean Up → Merge By Distance | Merge vertices based on their proximity. |
| Mesh → Clean Up → Fill Holes | Fill in holes (boundary edge loops). |
| Select → Select All By Trait → Non Manifold | Select all non-manifold vertices or edges. |
| Mesh → Split → Selection | Split off selected geometry from connected unselected geometry. |
| Mesh → Separate → Selection | Separate selected geometry into a new mesh. |

TABLE III: Suggested operations in Blender during mesh cleaning and separation.

*2) Re-topology:* re-topology is the process of creating a new, clean, and optimized 3D mesh topology over an existing and often more complex 3D model obtained from sculpting or 3D scanning. This step is time-consuming. However, it can be aided by automated tools. We recommend Quad Remesher [6]. Semi-automated tools such as Retopo-flow [7], an add-on in Blender, can also be of assistance to modelers.

*3) Texturing:* this involves assigning realistic textures to the cleaned mesh. Assuming color information (e.g. albedo or diffuse) is not provided during 3D scanning, artists must make textures on their own to ensure instruments' models have a realistic appearance. The first step to instrument texturing involves UV unwrapping. In Blender, for example, UV unwrapping is achieved first by marking seam edges and then performing a UV → Unwrap operation. Performing a UV → Smart UV Projection, which automatically creates the UV map given a set of parameters, can make the process even simpler.

Fig. 6: Usable 3D model after mesh augmentations. Wireframe is displayed.

After creating the UV map, textures can be obtained in various ways:

- ***Existing or procedural materials***: this involves either (1) downloading licensed or unlicensed textures available online, or (2) using procedurally generated materials such as shader nodes in Blender. We recommend this option for modelers who wish to achieve a decent effect in a relatively short amount of time.
- ***Texture projection***: images of the instrument are projected onto the 3D mesh, yielding diffuse colors on the said mesh. It requires a set of projected images captured under several soft, neutral light sources and bereft of shadows. Texture projection can only obtain the diffuse texture; normal texture or other advanced effects can only be obtained manually.
- ***Manual painting***: this time-consuming process involves an artist manually painting textures onto the mesh. The final result's realism depends entirely on the artist's skill.

*4) Animating:* our project concept involves pairing each instrument with an animation that separates it in its constituent parts - a "decomposition" animation - as well as an "in-use" animation displaying the instrument's appearance when it is operated.

- ***Decomposition animations*** require instruments to be separated into their components (or functional parts). Due to the mode of user interactivity, this decomposition must display the instruments components slowly drifting away from one another - and slowly gathering back into the original model.
- ***In-use animations*** require a display a functionality. In Figure 6, for instance, we animate the stereoscope to be mounted with a stereo pair. Instruments which themselves do not significantly change appearance when operated might also be paired with animations of the "unseen" - electric arcs flowing through a battery or galvanometer, for example.
- ***Sound effects*** should also be embedded into the in-use animations, where appropriate. In Unity engine, this can be achieved by attaching audio sources to animation scripts.

*5) Information binding:* additional information or notes related to history, function, and condition of models in the CSI should be attached to instruments' models. Program designers can consult the CSI's curators or access keywords in the metadata to set up a table storing this information. Animators should then consult this table to retrieve information and pair it with instruments on screen. For our stereoscope model, for example, we pulled historical information and information about a missing lens from the metadata, augmented this with usage information found online, and displayed all three in our animation.

## VI. Design Elements

Before showing how this data affects user flow with our Figma and Blender prototypes, we present the finer design elements of the Magical Cabinet of Curiosities.

1) Color Palette: Our design aims to prioritize a muted, scholarly color scheme to reflect the educational and historical nature of instruments on display. We wanted to effect a calm rationality in the virtual environment. Interface colors were mainly grayscale, using shades of black, white, and grey.
2) Typography: The style, arrangement, and appearance of text plays a crucial role in our design. We opt for Arial, a font celebrated for its readability and simplicity. This font ensures all text information is legible on our device interface. Total text permitted to appear on the screen simultaneously is kept to the bare minimum required for user comprehension in all layers except the Instrument Layer to avoid distraction. Even in the Instrument Layer, however, the user can "remove" text by rotating the handrail.
3) Layout: Our four-layer structure and Instrument Layer interactivity shift means the layout of instruments needs careful consideration. The aim is for the layout to guide users' eyes seamlessly and help them easily connect their physical rotation to virtual rotation. Consistency between the non-Instrument Layers ensures the user need not "re-learn" how to navigate. On the Instrument Layer, a single scientific instrument's 3D model dominates the view, while other instruments may only appear in a ribbon at the bottom of the screen. Size, then, communicates which instrument users can interact with on the Instrument Layer.
4) 3D Models: The actual instruments are always represented as 3D models with light maps and texturing. Other than the Top Layer, where each category is represented by an ever-cycling set of representative instruments (and the instruments scale larger and smaller as they cycle), and the Instrument Layer, where the selected instrument grows and others may only appear as small icons at the bottom of the screen, the instruments are sized similarly intra-layer.
5) Breadcrumbs: At all times, users can orient themselves within the experience's "funnel" based on the circles at the top left of the Object Navigator's screen. This subtly enforces the "funnel" concept in the user's mind, teaching him or her about the layered flow with symbols rather than words.
6) Environment: While our prototypes show the instruments without a background environment, we believe the instruments should be displayed in a historical anatomy lecture hall (see Figure 7 for an example). This ties in with the history of scientific display before the public (Figure 8). It is also austere, which means it will not distract the users from the instruments. And of course, users are "dissecting" the instruments in the Instrument Layer - it is fitting that they study anatomy where many have studied it before. As for the placement of the instruments, they will be atop an unremarkable wooden table (as in Figure 13) so as to minimize distractions; by the same token, the anatomy lecture hall background will be blurred.
7) Visual Pointers: Two minor visual cues assist with user flow. First, at every layer of the experience there are light blue arrows on screen indicating to the user their ability to interact with the virtual display via rotation (note that these are present in Figma if not in our animation). We include these arrows primarily so the user understands the Instrument Layer has several modes of functionality that can be achieved via rotation (rotation's functionality is more obvious on other layers due to the circular layout). To explain the second cue, we first note that the user uses two physical buttons outside of the Object Navigator screen to navigate between layers in our experience (this will be further explained in the next section). These buttons will have backlights. However, in the uppermost layer, the button used to move "up" one layer will no longer have a backlight. Similarly, the button to dive one layer "down" loses its backlight in the bottom layer. These cues indicate to the user that the buttons have reached their limit for navigation. Of course, the backlights reactivate once the user exits the top or bottom layers.
8) Sound: We foresee different sound cues to assist with navigation. For instance, the installation emits a soft hum when the displayed color lines fade out and back in, alerting the user to the updated instrument linkages. When users rotate our device for selection, we simulate the sound of a moving wheel to signify motion, which ceases when the rotation stops. Pressing the forward and backward buttons affixed to the handrail trigger a brief and bright "click" sound effect, indicating successful layer transition. Last, because instruments can appear animated and "in-use" in the Instrument Layer, each instrument will emit accurate sound during this animation (when appropriate), increasing user immersion and knowledge.

## VII. Prototyping

Our prototype interface consists of two parts: the lower section, isolated in Figure 9, represents the user's options

Fig. 7: Anatomy Hall Photo: Visual Inspiration for Virtual Environment

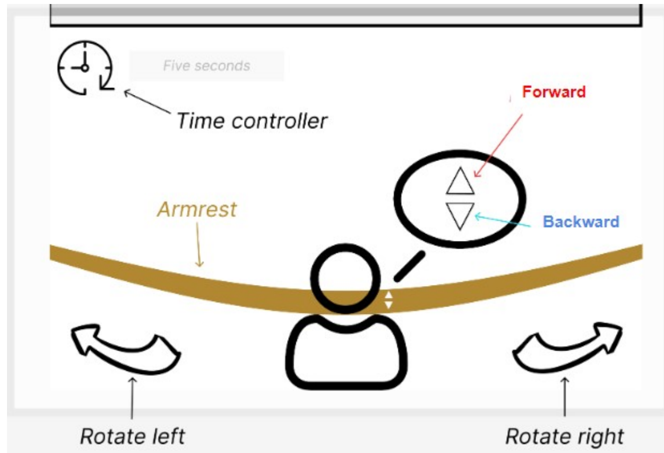


Fig. 9: Controller box in Figma. This simulates the user's functionality (or time's functionality). It is NOT part of the installation's virtual display.

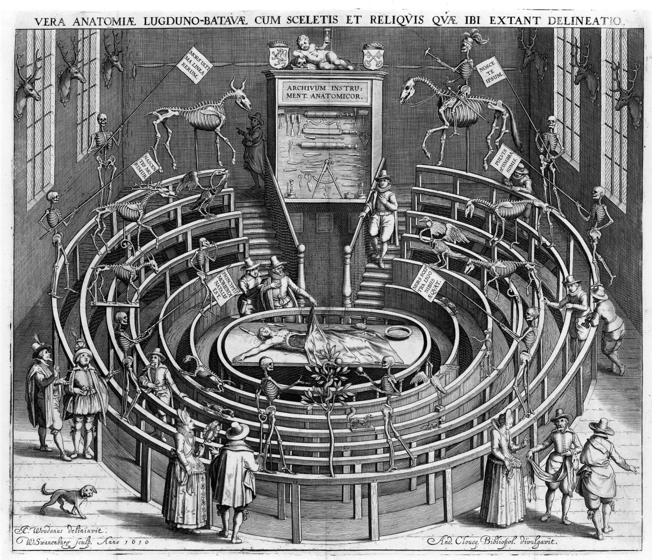


Fig. 8: Anatomy Hall Engraving from 1610 [8]: Thematic Inspiration for Virtual Environment

for interaction, while the upper section (area with a grey background in Figure 11, for example) represents the view on the Object Navigator's 3D screen. We dub the former the "controller box."

### *A. Controller box*

A clear distinction must be made between the physical controller of the installation and the virtual controller of the prototype. The former is the controller users would use to navigate our experience were this installation implemented. The latter is the controller we utilize to navigate the Figma prototype. To be abundantly clear: the controller box pictured in Figure 9 is not part of the Object Navigator screen. It is a tool we use to communicate user flow.

Our real-life controller consists of the Object Navigator's armrest and two buttons affixed to the armrest. Users can spin the entire device by rotating the armrest. Both buttons are located on the armrest, positioned between the user and the screen. The buttons are parallel to the floor and in the shape of arrows; one button points toward the screen, the other, toward the user. We call these the "forward" and "backward" buttons respectively. Figure 9 labels these two buttons and portrays their shape and orientation.

The "rotate left" icon corresponds to the user turning the device left, while the "rotate right" does the same for the opposite direction. Moreover, the button labeled "five seconds" simulates the passage of five seconds (this is not a functionality users can activate). We cannot operate these buttons in this report but we present them nonetheless so the options for user activity (or inactivity) are clear.

### *B. User Flow*

We return to the layered "funnel" introduced above. Our user flow - depicted conceptually in Figure 10 - is dominated by this structure.

1) Top Layer: The user's journey with our device begins at the Top Layer. Here, sixteen ever-rotating circles of 3D models represent sixteen different types of scientific categories. These circles are themselves organized around the edge of a large circular table; the virtual perspective is fixed on the center of the table, as viewed from the side. See Figure 11 for a Figma depiction.
   As time passes, each category-specific circle rotates clockwise. Instruments grow in size as they approach the top of their circle and decrease in size as they reach the bottom. At the bottom, they vanish completely, and new instruments "emerge" from the other side of the vanishing point. The idea is to dynamically showcase "representatives" from each scientific category to the

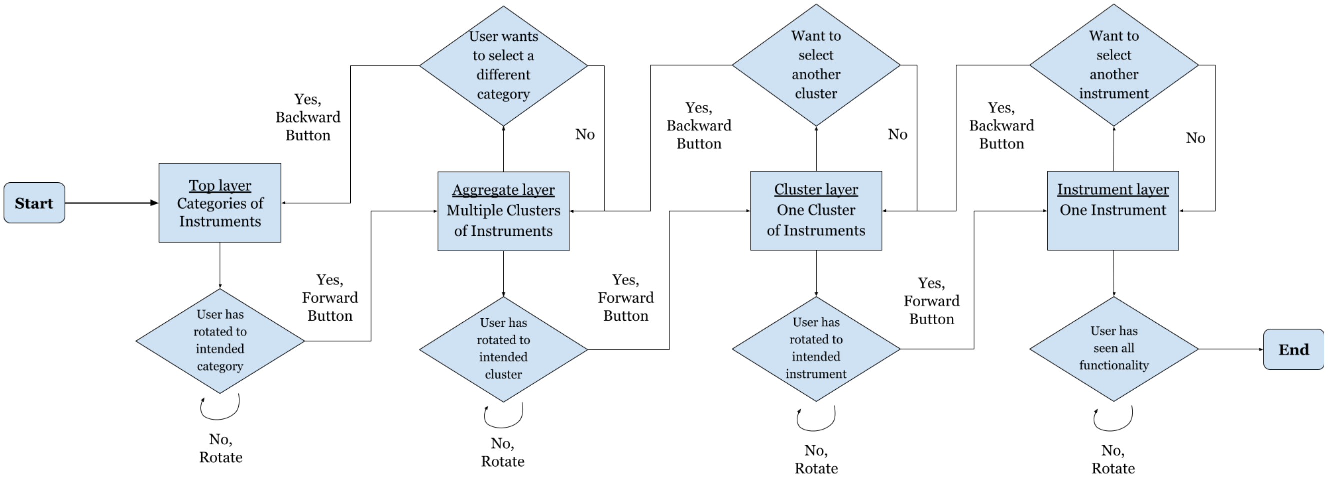


Fig. 10: Flow chart for users


Fig. 11: Top Layer

user while her or she is deciding which category to select.

"Selecting" a category amounts to pressing the forward button while the virtual perspective is in front of the said category. To communicate to the user which category they are about to select, we display the name of the five categories closest to the user's perspective beneath the representative circles, making the to-be-selected category's name largest. Should the user wish to select a different category, he or she can rotate the armrest to rotate the virtual perspective. Clockwise user rotation results in the virtual perspective "walking" clockwise "around" the virtual table. In other words, the virtual perspective is always fixed on the center of the table, and rotation simply changes which side of the table the virtual perspective views this center from.

Once the user identifies their desired category, rotates toward it until their virtual perspective is in front of the category, and presses the forward button, they move to the Aggregate Layer.

2) Aggregate Layer: Upon selecting a category, all category circles vanish except the one the user selects. This selected category then expands and fills in the virtual table with sixteen (or less) circles of 3D models (see Figure 12). These circles of instruments are the intra-category clusters derived from the clustering algorithm described above; though small, every 3D model within a category is technically visible in the Aggregate Layer. If there are less than sixteen circles of 3D models, they fill in adjacent spaces on the table, ensuring the user never has a need to navigate empty space.

Rotation and the forward button have exactly the same functionality as before. The backward button brings the user back to the Top Layer. If the user finds a cluster that interests them, they can press the forward button to move to the Cluster Layer. Alternatively, they can wait. If they do, they will see colored lines begin to appear on screen.

These lines represent object linkages recovered from

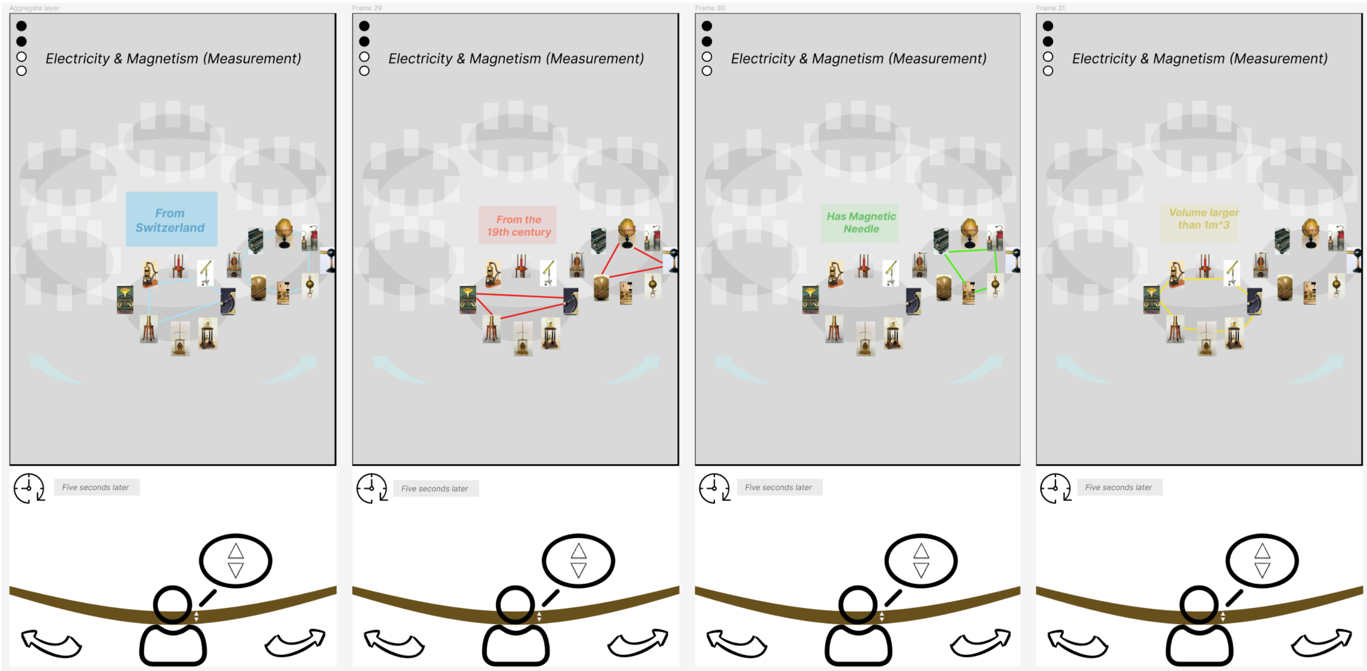


Fig. 12: Aggregate Layer with various linkages

metadata after clusters are derived. Again, this process is explained above. These colored lines are unaffected by user rotation. Instead, the lines gradually fade in and out such that every five to ten seconds, a new set of lines linking instruments along a different dimension is visible. The lines may connect anywhere from two to all sixteen objects within a cluster, and they may appear in different clusters simultaneously. They may not connect instruments from different clusters. Importantly, they are always accompanied by textual explanations. For example, if a blue line appears with the text "from Switzerland", it indicates all instruments connected by the blue line are from Switzerland. Similarly, in Figure 12, instruments connected by a red line are instruments invented in the 19th century.

Our utilization of an unsupervised clustering method to group these instruments aims to efficiently make sense of a layer that includes all instruments, ensuring the interface's tidiness and aesthetic appeal. Simultaneously, the colored lines clarify in part our clustering methodology. Given that the unsupervised clustering method considers a group of characteristics, individual colored lines might not sufficiently rationalize the groupings. However, the combination of unsupervised clustering and colored lines strikes a balance between the arbitrariness of a historical curiosity cabinets and the rigidity of fully supervised groupings, demanding less from the user while affording them the joy of discovery.

3) Cluster Layer: As before, once the user selects a cluster in the Aggregate Layer, all other clusters vanish while the selected cluster grows and expands to fill up the virtual table (see Figures 13 and 15). Rotation functionality, button functionality, and time-based linkage behavior persists between the Aggregate and Cluster Layers. However, there are two notable differences. First, a maximum of sixteen instruments are on display

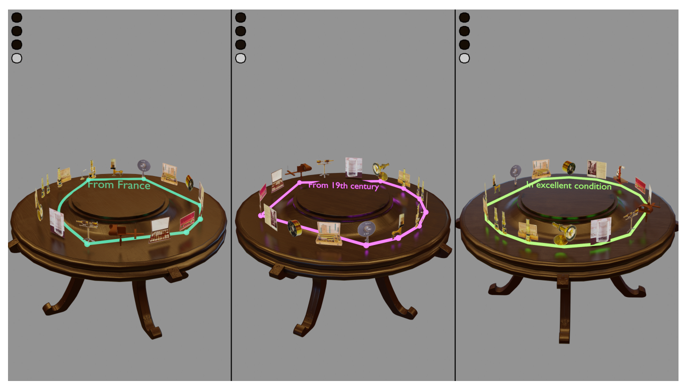


Fig. 13: Cluster Layer rendered in Blender


Fig. 14: Instrument Layer rendered in Blender

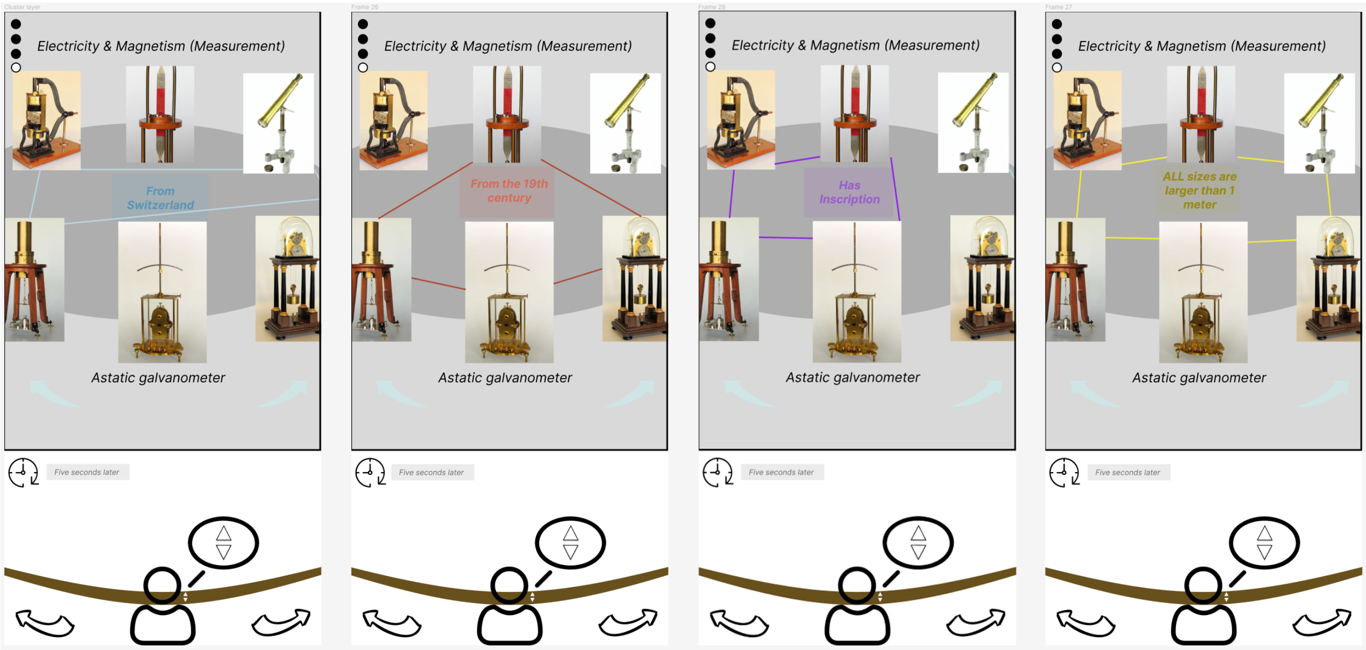


Fig. 15: Cluster Layer with various linkages

in the Cluster Layer (compared to a maximum of $16^2$ in the Aggregate Layer). The instruments will therefore be large enough for users to genuinely observe for the first time. Second, the instruments in the Cluster Layer are all animated to be "in-use." This, along with ongoing instrument linkages, should motivate the user to select (with the forward button) an instrument for further inspection.

4) Instrument Layer: This is the final layer of our experience. When users select an instrument in the Cluster Layer, it floats above the table and brings the virtual perspective along with it until the table and other instruments are out view (see Figure 14). Text displaying historical information about the instrument, selected by the CSI's curators or extracted from our metadata file, floats beside the instrument in virtual space. Meanwhile, horizontal ribbons displaying linkages to several other instruments cycle in and out of frame at the bottom of the screen, maintaining the presence of linkage information but perhaps not limiting possible linkages to the current cluster.

   For the first time, user rotation no longer corresponds to rotation of the virtual perspective. Indeed, that the selected instrument begins to slowly rotate on its own as soon as the user has entered the Instrument Layer attempts to communicate this fact to the user. Instead, user rotation activates different ways of viewing or manipulating the instrument. If he or she moves counterclockwise away from the "start" of the Instrument Layer, the text and linkage ribbons will slowly disappear while the object simultaneously begins to "explode" into its constituent parts. At 90 degrees of rotation the instrument will be fully decomposed, and text will again appear to point out parts of interest - inscriptions or broken elements, perhaps. Continued rotation gradually reassembles the instrument while activating a zoom, reaching full zoom (and an appropriately scaled ruler at the bottom right of the screen) at degree 180. The last functionality of the Instrument Layer gradually occurs as the user continues to rotate: animation. At degree 270, the instrument is in full animation, displaying what it looks like while in-use alongside appropriate sound effects. Continued rotation brings the user back to the "detail and linkage" view that appeared when they first entered the Instrument Layer. The full life cycle of rotation in the Instrument Layer is visible in Figure 16.

The user is at any point able to navigate between the different layers of our experience using the backward and forward buttons (see Appendix Figure 1 for a visual depiction of inter-layer traversal). This flexible navigation system ensures a seamless and interactive user experience, enhancing the educational potential of our device. It also means user can visit and revisit the Instrument Layer as many times as they wish, granting the CSI broader exposure.

In Appendix Figures 2 and 3 we include visual depictions of the rotation functionality and time-based linkage formation. Finally, we include an all-encompassing visual depiction of user flow in Appendix Figure 4.

## VIII. Next Steps & Alternative Design Choices

Implementing this installation to its fullest extent would first require designers to create 3D models for every instrument in the CSI and every instrument's constituent parts. Animators

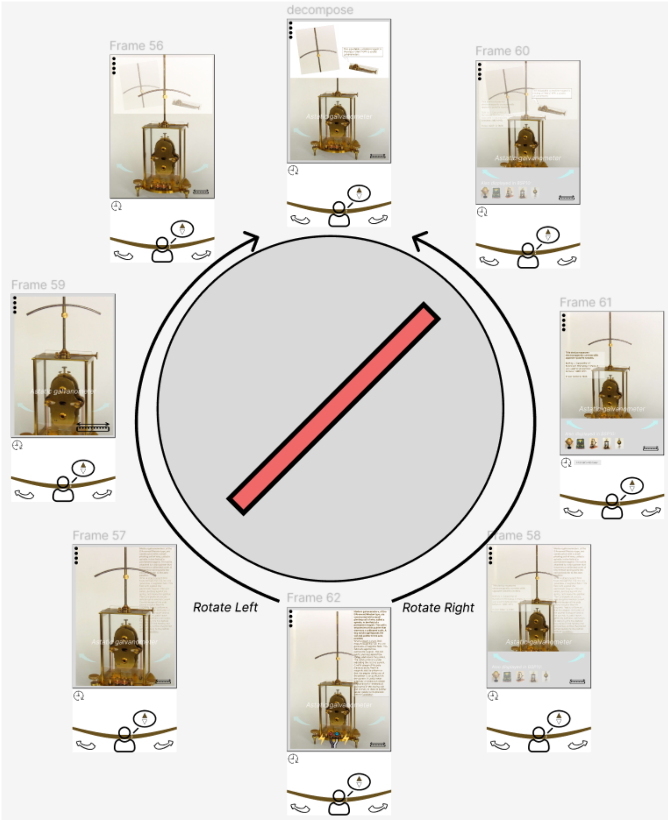


Fig. 16: Full cycle of rotation-based functionality in the Instrument Layer. The user is placed at degree 0 (cardinal direction east) upon selecting an instrument and moving into the Instrument Layer. Counterclockwise rotation then gradually decomposes, zooms in on, or animates the object, depending on the user's location.

would need to animate each 3D model to show the instruments' appearances while in-use, and sound engineers would need to pair these animations with sound effects where appropriate. Our proposed historical anatomy lecture hall virtual environment would also need to be developed.

To realize the clustering aspect of our experience, the core variables involved in our clustering pipeline - particularly the dimensions measurements - would need to be filled in and have formatting standardized as much as possible. Filling in and standardizing variables beyond this core set would be helpful for establishing the linkages displayed in the lower three layers of our experience, though the absence of all possible linkages does not pose as much of a barrier to the projects immediate implementation.

On the Instrument Layer, curators would need to decide on descriptions and details to present to the user via text, especially if the desired information is not already contained in the metadata present on the website. Animators would need access to the information being displayed in order to understand which parts of each object need visibility in the "decomposition" stage of the Instrument Layer.

While we are proud of developing a system which we believe displays the entire CSI in an intuitive way, we understand there may be a desire to incorporate less layering into the user flow. One option to accomplish this is to simply remove the Top Layer and require users to navigate within one category of objects during their experience. One might imagine this installation as part of a larger exhibition on the CSI, in which case the Magical Cabinet of Curiosities could show off, for example, optical instruments exclusively. In this case, the backward button could obtain an additional functionality on the Aggregate Layer: the ability to 're-shuffle' clusters by recalculating Gower's distance with a different distribution of weights assigned to the cluster variables. Another option for removing layers is to settle on a much smaller subset of instruments for display and then to remove both the Top and Aggregate Layers from the experience. In this case, linkages to other objects in the CSI could still be shown on the linkage ribbon in the Instrument Layer even if they are not available in the Magical Cabinet of Curiosities, and the set of instruments on display could change each week or even day.

We employ a circular layout in the Top, Aggregate, and Cluster Layers to link our virtual display to the user's physical navigation and prevent a scenario where the user must relearn how to navigate in each new layer. Nonetheless, we can think of an alternative Top Layer which would be thematically fitting and perhaps more exciting for the user and curators. Instead of rotating around a circular table as in the Aggregate and Cluster Layers, the user's rotation in the Top Layer could move the virtual display along a preset path within a historical cabinet of curiosities. The ever-cycling representative circles would then be found in various nooks and crannies around the room (see Figure 17 for a simple visualization). Visual elements in other layers could follow suit to emphasize the scientific oddity theme; for example, the scale-establishing ruler in the Instrument Layer could be replaced with a piece of fruit affectionately dubbed "Newton's Apple".

Finally, if curators believe the on-screen arrows indicating the user's ability to rotate are too subtle to ensure users explore the functionality of the Instrument Layer, the ground surrounding the Object Navigator could physically indicate the description, decomposition, zoom, and in-use zones of the circle - with backlighting that only activates when the user has navigated to the Instrument Layer.

There is an inherent tug-of-war between (1) the arbitrariness of historical cabinets of curiosities and user comprehension of our instrument organization, (2) extended virtual functionality and limited physical avenues for user interaction, and (3) the allure of onscreen and offscreen visual elements. We try to emphasize user understanding, agency, and attentiveness with our design choices, and present the aforementioned alternatives in the case CSI curators believe other desired outcomes need more emphasis.

## IX. Conclusion

The Magical Cabinet of Curiosities accesses untapped educational and downright fun possibilities with an EPFL- and

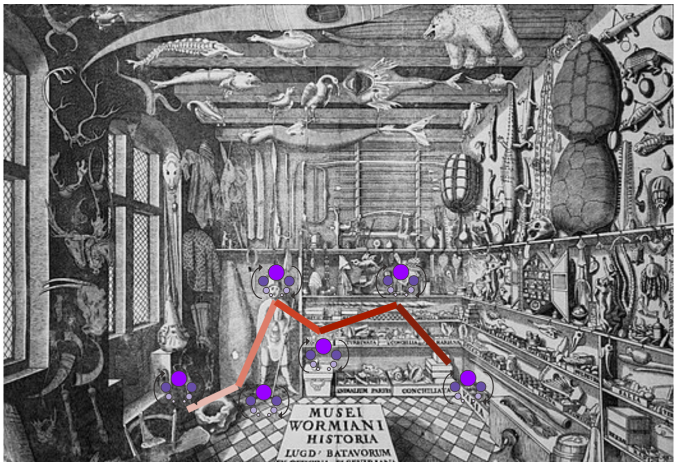


Fig. 17: Alternative Top Layer. Clockwise user rotation corresponds to movement from bright red to dark red; ideally the path would constitute a complete loop around the virtual room.

UNIL-managed collection that remains somewhat out of the public's reach due to the (necessary) "museumification" of its valuable instruments. By using backend metadata to develop a novel means of organizing the entirety of the CSI with four intuitive layers, we present an Object Navigator installation that gives users the power to play with and learn from accurate 3D models without the need for prior scientific knowledge or heavy time investment. Full implementation of our detailed 3D model development and animation pipeline should convince users of the CSI's untapped treasures and, ideally, proffer a sensation of wonder akin to that which pulls people toward the scientific field. As the potential for peculiar associations between instruments invokes in part the Cabinet of Curiosity of the past, our installation will ground the aforementioned sensation in the long history of scientific display through suitable echos from the past.

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## Appendix

| Name | ID | From France | For Recr. or Educ. Use | For Demos | Owned by UNIL | Owned by a Museum | In Excellent Condition | In BSP10 | From late 19th century | Has Inscription(s) |
|---|---|---|---|---|---|---|---|---|---|---|
| Stéréoscopes américains (type Holmes) | 603.0079 | | | x | x | | | | x | |
| Boîtes de 48 échantillons cristallins | 603.008 | | | x | x | | x | | | x |
| Cristal biréfringent (rhomboïde de spath d'Islande) | 603.0322 | | | x | | x | x | | | |
| Chambre claire (pour le dessin d'après nature) | 603.0326 | x | | | | x | x | | | x |
| Prisme oscillant (Secretan) | 603.0329 | x | | x | | x | x | | x | x |
| Lot d'anaglyphes | 603.0452 | x | | x | x | | x | | | |
| Cristal biréfringent | 603.0472 | | | | x | | x | | | |
| Jeu d'oculaires pour lunette | 603.0498 | | | x | | | x | | | |
| Objectif de projection | 603.0551 | x | | x | x | | | | x | x |
| Appareil de projection pour les phénomènes de pol. | 603.0583 | x | | x | | | x | | | x |
| Polyprisme sur support | 603.0724 | | | x | x | | | | x | |
| Grand microscope à tambour | 603.0834 | x | | | x | | x | x | x | x |
| Microscope à niche | 603.0837 | | x | | x | | x | x | x | |
| Microscope à niche | 603.0839 | | x | | x | | x | x | x | |
| Microscope à niche | 603.084 | | x | | x | | x | x | x | |
| Microscope à main, de démonstration | 603.0841 | | | x | x | | x | x | x | x |

TABLE IV: Sample cluster from the Optics category. This set of instruments appears together on the Aggregate and (if selected) Cluster Layers; the linkages displayed here are a subset of all possible linkages.

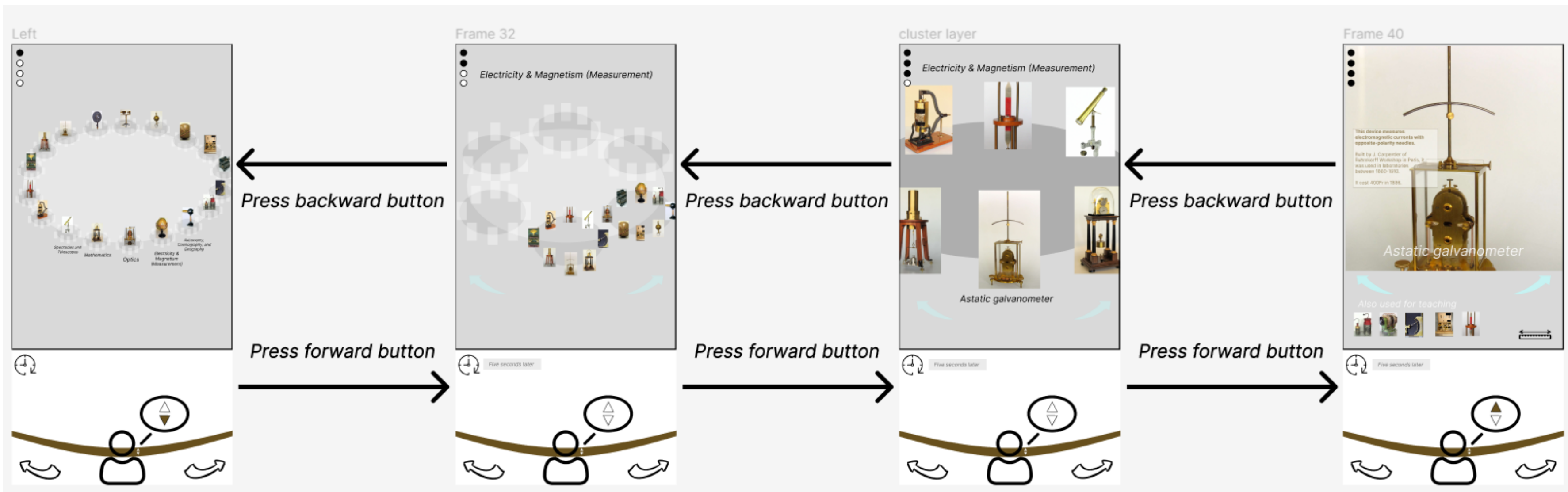


Fig. 1: Inter-layer user traversal. The user moves between layers using the physical buttons located on the Object Navigator's armrest. The backward button's backlight disappears in the Top Layer, while the forward button's backlight disappears in the Instrument Layer, signaling the limits of user navigation.

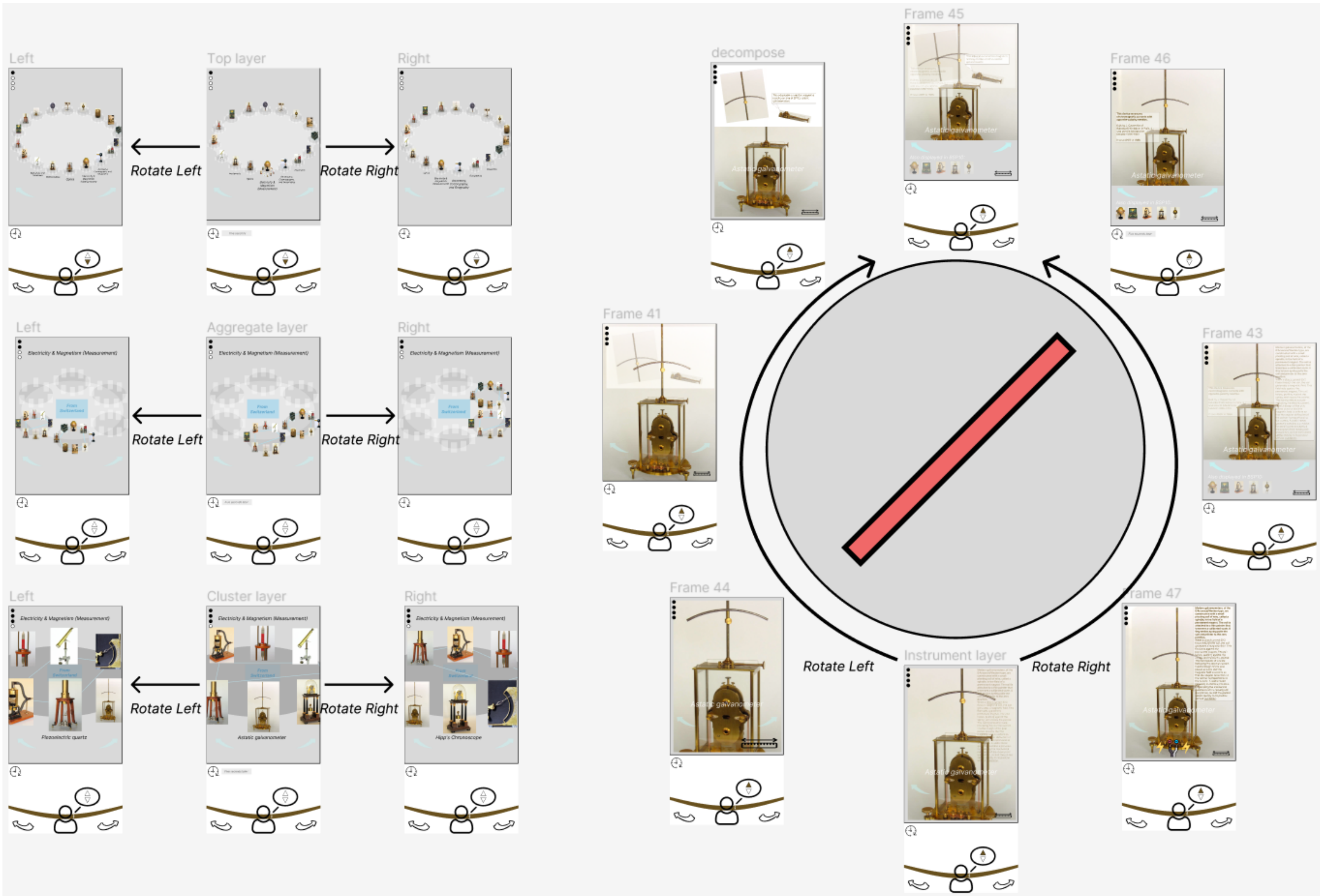


Fig. 2: Intra-layer rotation functionality. The user rotates the display by moving the armrest.

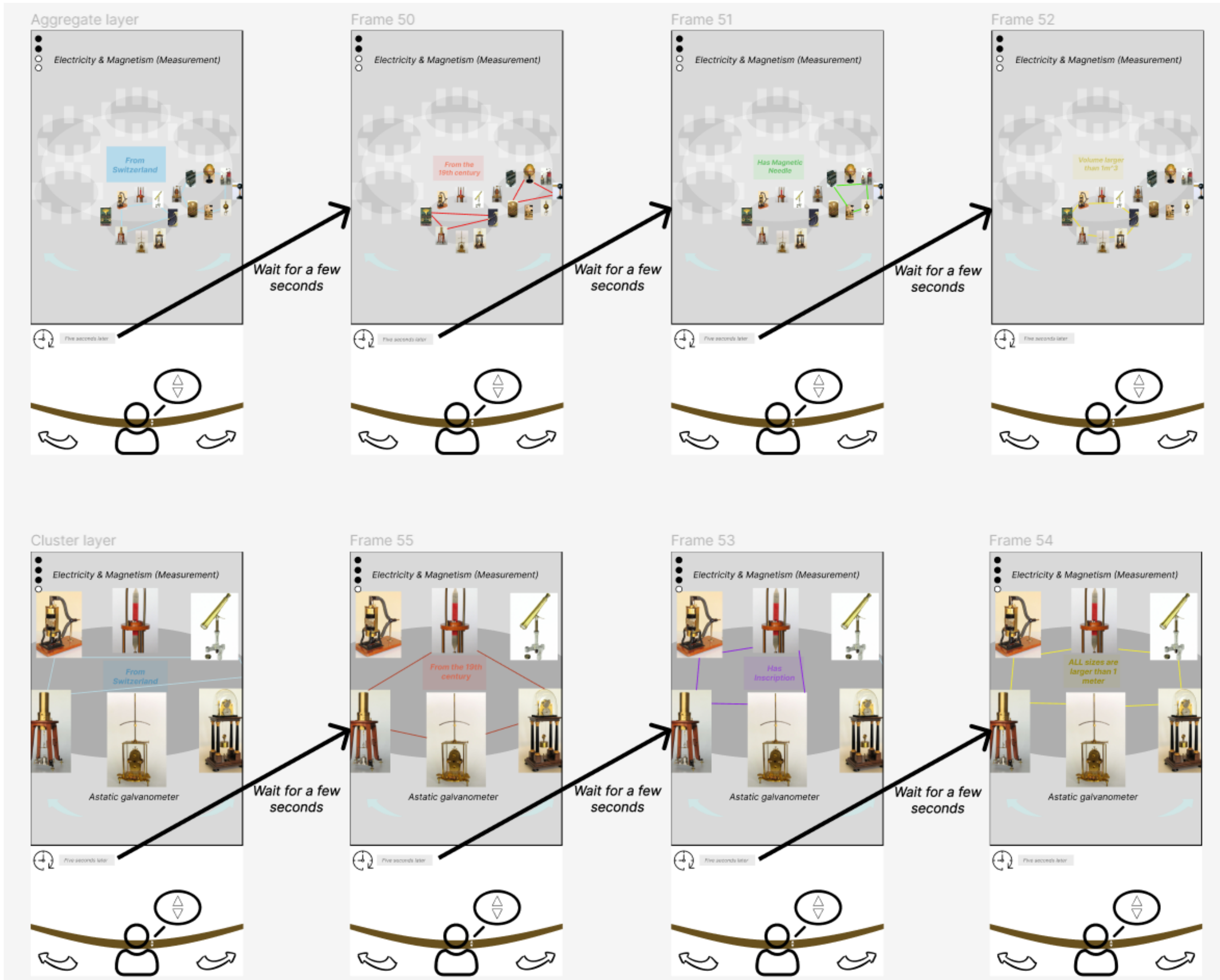


Fig. 3: Intra-layer time functionality. Each black arrow corresponds to the effect of the passage of a few seconds. Users cannot interrupt the linkage cycling unless they use the buttons on the armrest to navigate to the Top or Instrument Layers.

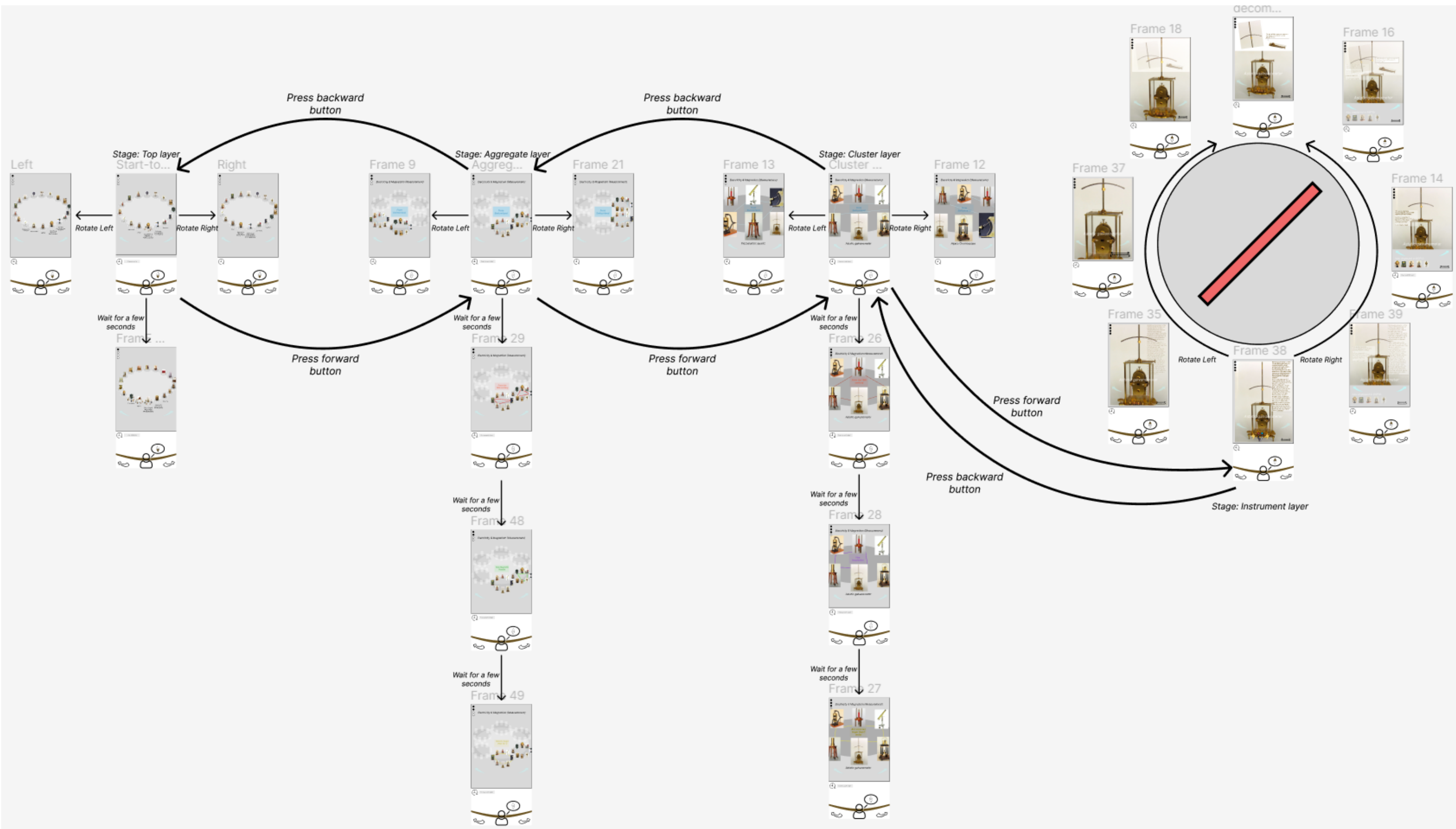


Fig. 4: Global visual depiction of user flow throughout the Magical Cabinet of Curiosities.