CUBED

REPORT

CS147 Winter 2021

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Overview

Value Proposition: Collaborate and build in 3D with ease.

Our team consists of:

- Krain C. | Designer & Mobile Developer
- Nicholas B. | Mobile & Web Developer
- Nicholas V. | Designer & Augmented Reality Developer
- Zoey Z. | Product Manager & Mobile Developer

Note from the team:

Coming from diverse backgrounds of computer science, graphic design and humanities, we all dove into this project with a mindset open to learning, encouragement, and growth. With each member at different points in their respective educational career, we understood the perspectives and tools that we could each bring to the table. Together, we embarked on this journey to solve a problem related to educational learning in virtual/augmented reality. And, despite having limited experience with VR/AR, we jumped right in with excitement.

The following report summarizes our findings throughout the ten-week quarter and highlights the final product. What is not depicted, however, is the experience, fun, and interactions we all had with those related to the project. We'd like to extend a special thanks to all our interview participants that helped us along the way as well as our TA, Taylor L., for guiding us throughout this journey.

Central Problem and Solution

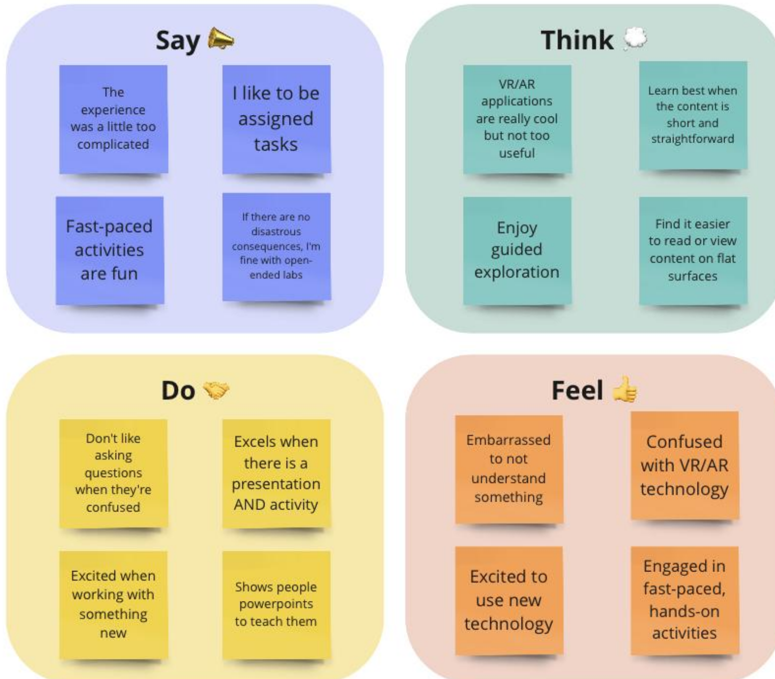
Mission Statement: Enable immersive learning through defying space.

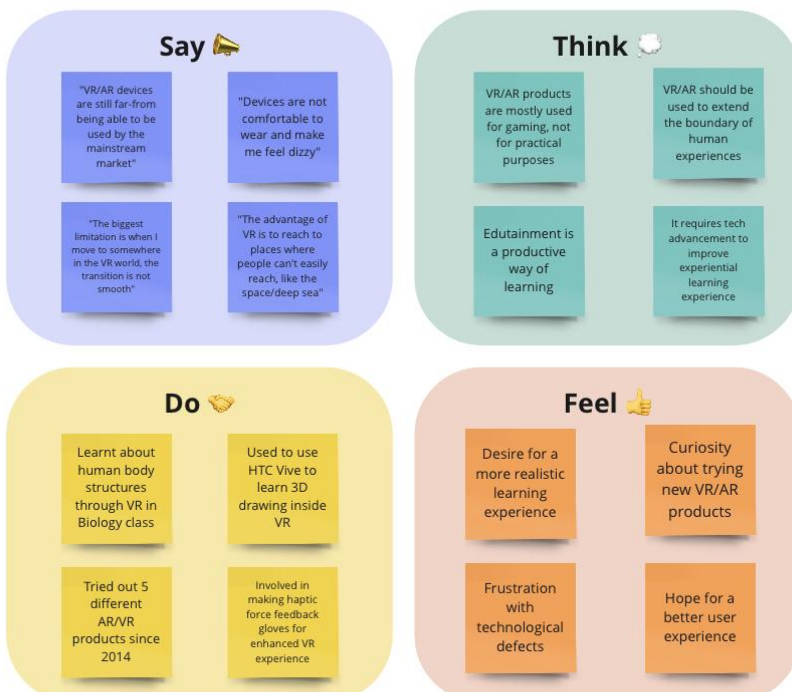
Problem: Virtual learning can be difficult when you're limited to video-calling or screen sharing in two-dimensions. Especially for abstract concepts or those that require complex visualizations, people have a hard time getting their point across, much less learning new topics or building on top of the work of teammates.

Solution: Cubed aims to solve this problem by providing a workspace where you can efficiently demonstrate concepts and collaborate with others in 3D. Add shapes/objects, annotate, or draw in 3D to teach others through a "hands-on" experience. And, with augmented reality mode, users are able to view their creations right there in their space.

Needfinding Interviews

We conducted our needfinding interviews through focusing on experiential learning. In choosing such a broad category, we interviewed an equally diverse range of participants ranging from students and teachers to developers in the field of VR. Compiling each of our interviews together we created empathy maps to summarize and aggregate the findings of each interview. For the sake of privacy, we will not include the pictures of our interviewees, but below are some excerpts from our empathy maps, with only some of our findings included for the sake of conciseness and readability.


Say
The experience was a little too complicated
I like to be assigned tasks
Fast-paced activities are fun
If there are no disastrous consequences, I'm fine with open-ended labs
Think
VR/AR applications are really cool but not too useful
Learn best when the content is short and straightforward
Enjoy guided exploration
Find it easier to read or view content on flat surfaces
Do
Don't like asking questions when they're confused
Excels when there is a presentation AND activity
Excited when working with something new
Shows people powerpoints to teach them
Feel
Embarrassed to not understand something
Confused with VR/AR technology
Excited to use new technology
Engaged in fast-paced, hands-on activities


Say
"VR/AR devices are still far-from being able to be used by the mainstream market"
"Devices are not comfortable to wear and make me feel dizzy"
"The biggest limitation is when I move to somewhere in the VR world, the transition is not smooth"
"The advantage of VR is to reach to places where people can't easily reach, like the space/deep sea"
Think
VR/AR products are mostly used for gaming, not for practical purposes
VR/AR should be used to extend the boundary of human experiences
Edutainment is a productive way of learning
It requires tech advancement to improve experiential learning experience
Do
Learnt about human body structures through VR in Biology class
Used to use HTC Vive to learn 3D drawing inside VR
Tried out 5 different AR/VR products since 2014
Involved in making haptic force feedback gloves for enhanced VR experience
Feel
Desire for a more realistic learning experience
Curiosity about trying new VR/AR products
Frustration with technological defects
Hope for a better user experience

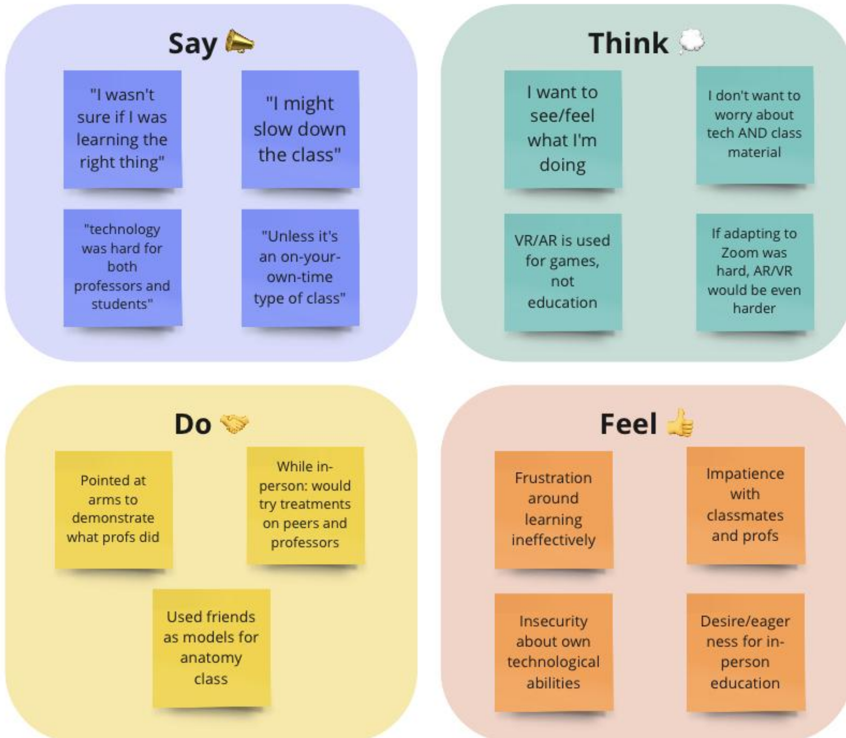


Figure 7: Sample empathy maps from needfinding interviews

From our interviews we discovered that one of the largest concerns was the accessibility and learning curve of VR technology for those who had little experience with some expressing much doubt toward the medium.

However, we also determined that most of the participants we interviewed were very open to the idea of this technology being used to complement the traditional classroom setting. Further needfinding interviews revealed that participants responded much more receptive to being able to learn concepts when they were given a hands-on experience rather than being taught abstractly or through a screen. Many participants also had a desire to try out otherwise impossible experiences such as space exploration through the media of VR. Moving on from here we wanted to use these interviews to create a fuller picture of each of our participants.

Point of View Statements and Experience Prototypes

The most influential insights we gained during our second round of interviews was with James and Emmy. While we created a Point of View (POV) for each of our interviewees, our final and most insightful POVs are as follows:

- We met James, a 50 year-old high school CS teacher.
- We were surprised to notice the way James used common household items to teach CS.
- We wonder if this means James feels like he can more effectively and creatively convey concepts to students using concrete or visual representations.
- It would be game-changing to provide teachers like James with visualization tools for teaching abstract concepts.

This POV led to several How Might We's (HMWs), including:

- How might we provide versatile physical tools to create visualizations?
- How might we encourage more interactive elements within learning visualizations?
- How might we capture the tactile nature of physical teaching implements in a digital space?

These HMWs felt somewhat too similar to each other, and so we learned from our first attempt and branched out with Emmy's POV and HMWs:

- We met Emmy, a 16 year-old high school student interested in product design.
- We were surprised to notice how she was unable to visualize physics principles as effectively as graphic design since her experience in the latter was more grounded in instinct.
- We wonder if this means she understands topics that are more creative and grounded in more personalized and self-intuitive understandings.
- It would be game-changing to incorporate more creativity in learning technical subjects and provide a less structured way of allowing students to discover their own understanding of design without explicitly teaching certain concepts.

This time, our HMWs were less focused on specific solutions:

- How might we encourage creativity in structured learning environments?
- How might we intuitively represent abstract concepts?
- How might we create better visualizations?
- How might we provide more versatile physical tools?

From these HMWs, we proceeded to brainstorm a variety of solutions, keeping an open mind and prioritizing quantity. We came together as a team to pick on the best solutions out of these, with each person who brainstormed the solution explaining exactly what they were envisioning for it. We then voted on our favorite solutions, and created experience prototypes for our top three solutions.

Solution 1 was a VR whiteboard in 3D space that allows every learner to inspect other's work. We simulated a virtual whiteboard in 3D space using a cardboard box. In this cardboard box, you're able to demonstrate and manipulate 3D objects while the other person can view what's inside. To test, we first taught someone how to make an airplane with a graphic. Next, we taught someone how to make one with the box.

The assumption we were testing was that people value hands-on learning even when being taught virtually. Although this prototype took some time to set up, it made visualizing things a lot easier. So our assumption was true: hands-on teaching can be valuable when visualization is critical to understanding; being able to see things in 3D space and having an instructor "right beside you" can make following directions and class participation more engaging.

Solution 2 was an AR/VR overlay with the current environment that allows the user to learn through self-driven exploration in an immersive environment. We simulated the "solar system" by creating a "space" decorated by paper cut planets and sticky notes. With minimal instructions, we invite participants to the "space" and observe whether/how they engage with it.

The assumption we were testing was that people are willing to learn through self-driven exploration. Our assumption was again true and the prototype worked well. Both participants engaged with the "solar system" prototype in a self-driven, exploratory way, and both participants indicated a high level of interest in experiential learning through self-driven exploration.

Solution 3 was a VR/AR Simulator where you're able to toggle different laws of physics and experience the effects. We simulated being on various planets by giving someone a weight (equal to how much an object weighs on different planets). Afterwards, we ask whether they intuitively understand that knowledge more and have better short-term recall.

The assumption we were testing was that people understand and retain conceptual information better when allowed to experience it. This time, the limitations of our prototype were that we could only test short-term memory. And our assumption was only partially true. The prototype made the concepts more intuitive, but the details are better recalled through non-experiential means.

Design Evolution

Choosing an Interface

From our experience prototypes, we found that being able to visualize complex topics greatly improved a user's ability to understand them and to build off another person's work on them. Thus, the final solution we came up with was a workspace where users can quickly demonstrate and collaborate with others in 3D. They can add shapes/objects, annotate, or draw in 3D to teach others.

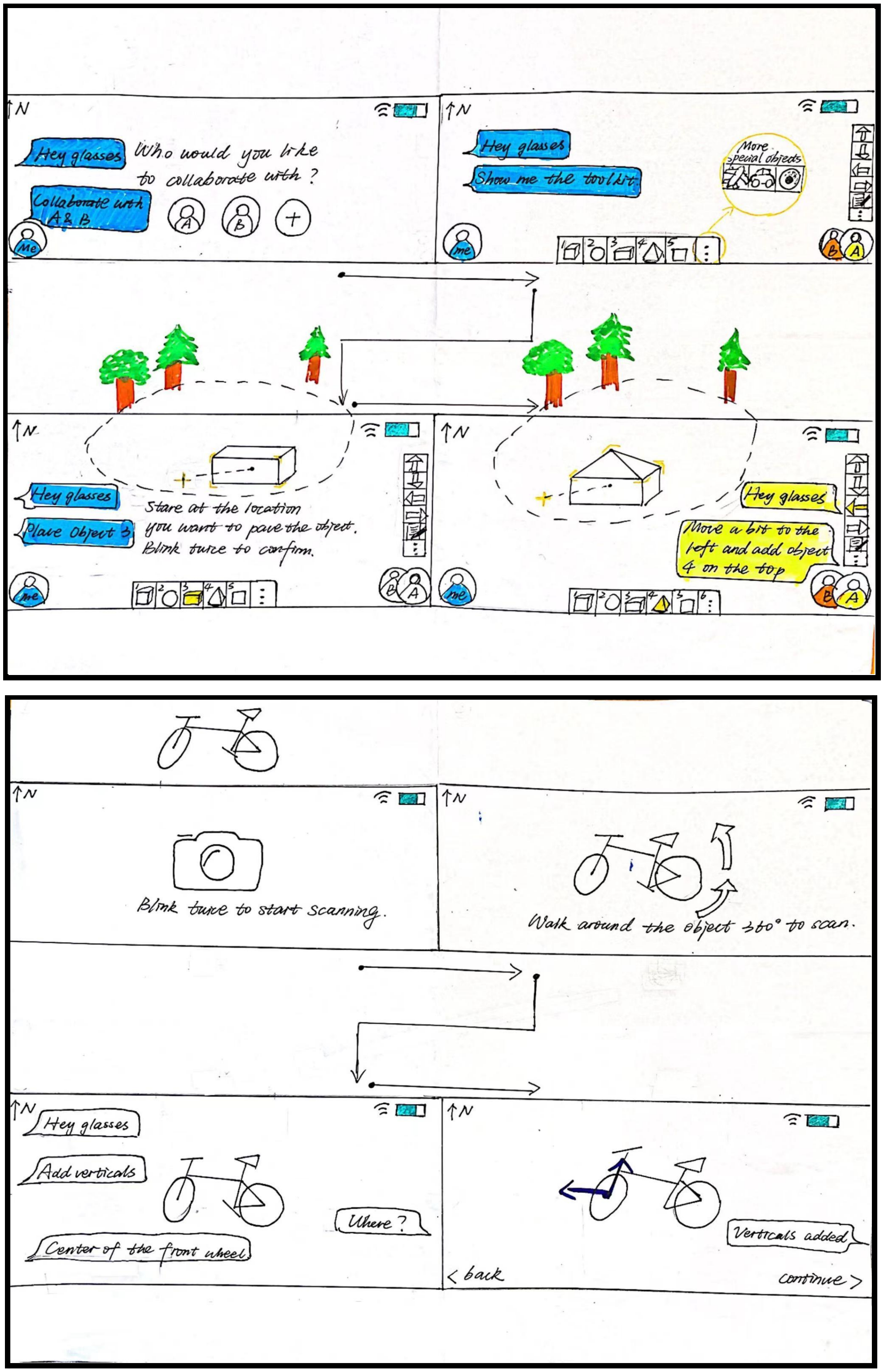


Figure 8: Mixed reality glasses storyboard

Ultimately we selected Voice-Controlled Smart Glasses as our final interface design and decided to move forward with developing and testing it. We believe voice control is intuitive for users especially with its similarity to existing speech recognition technologies. It is also more efficient than our VR controllers realization, which is one of our key measurements. Equipped with cameras and sensors, smart glasses allow the user to scan a model/3D object in real life, which has broader applications than importing a model from an existing library.

User Tasks

After choosing this interface, we defined our three tasks by levels of complexity:

Our simple task is to create in 3D. We chose this task because it is the foundation of our product and thus should be intuitive for users to perform.

Our medium task is to share one's work with others. A key part of Cubed is its ability to foster collaboration, so this task should also be relatively intuitive to perform, but sharing an existing workspace takes a few more steps and slightly more familiarity with the interface.

Our complex task is to review prior work history. This task is geared towards power users who may want to revisit version history to make or revert changes.

Low-Fidelity Prototype

Our low-fi prototype allowed us to complete an early (unrevised) version of the three tasks above: (1) presenting information, (2) collaborating with others synchronously, and (3) reviewing the workspace history.

1. To present information, we want the user to create a new workspace. Figure 9 outlines the process of creating, naming, and adding users to a workspace.
2. To collaborate with others, we want the user to open a workspace shared to them. Figure 10 outlines the process of opening a shared workspace and viewing changes committed synchronously by another user.
3. To review the workspace history, we want the user to view the timeline of the workspace. Figure 11 outlines the process of viewing the timelines and skipping through various points within the timeline.

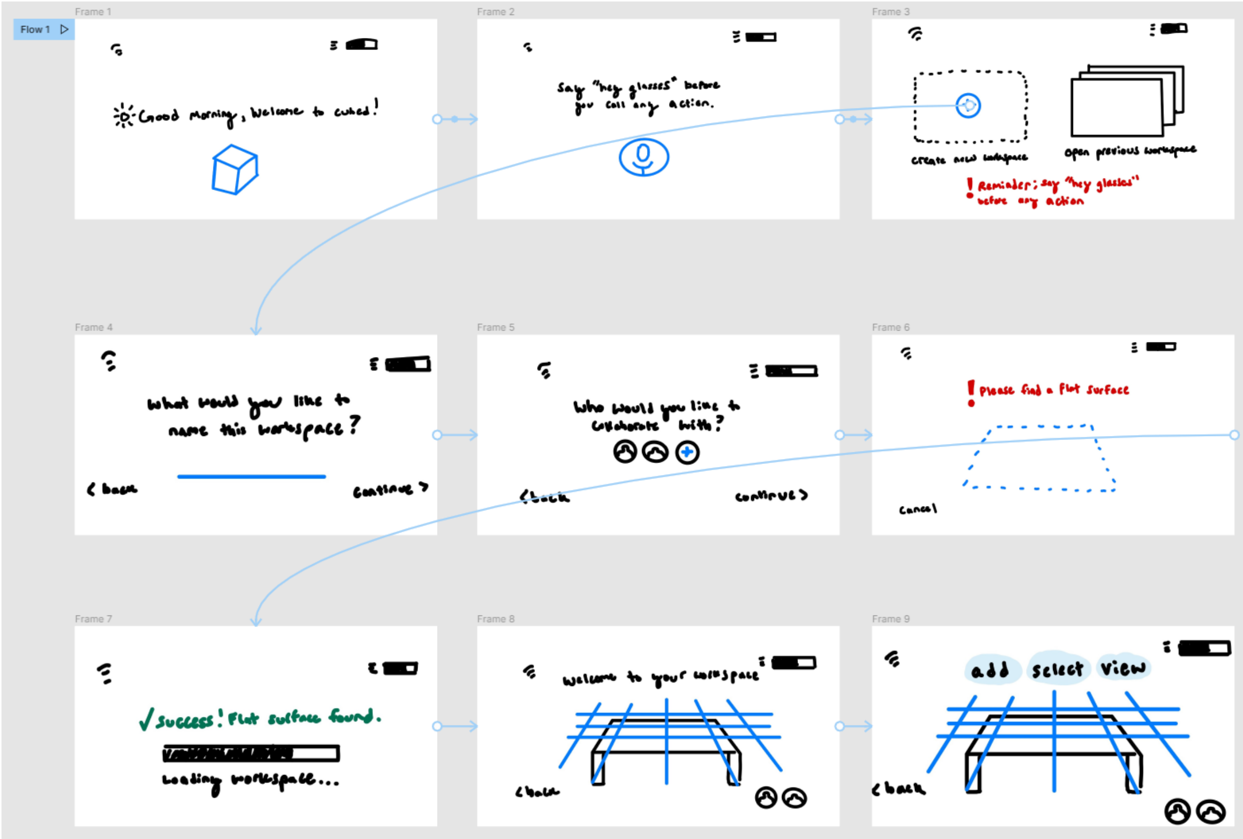


Figure 9: Present information through creating a new workspace

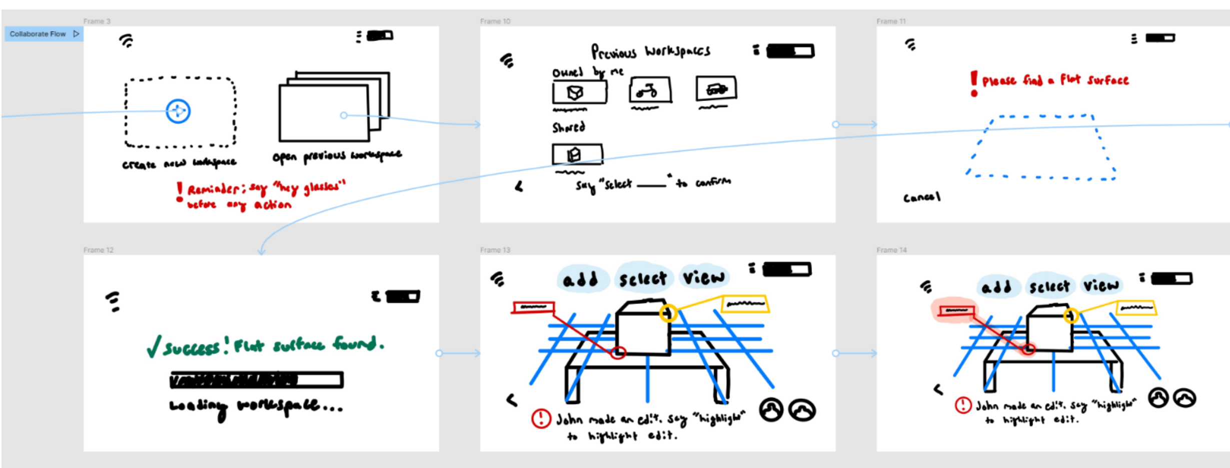


Figure 10: Collaborate synchronously by opening a workspace shared to you

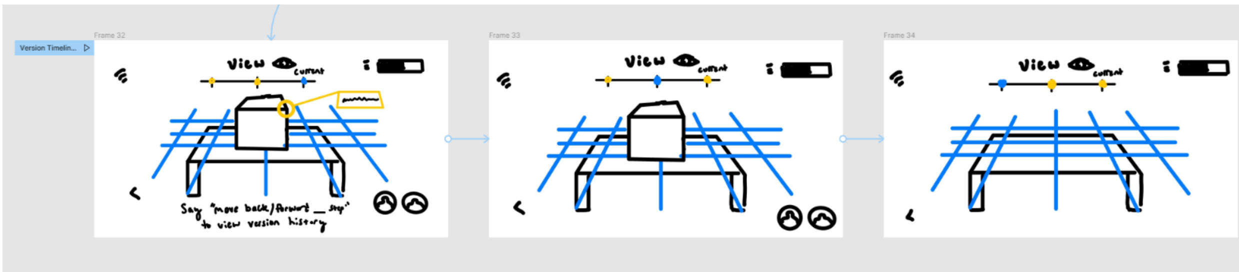


Figure 11: Review work timeline

In addition to the primary user tasks, we added functionality for adding objects and selecting objects. A user can place or select a cube or a post-it note.

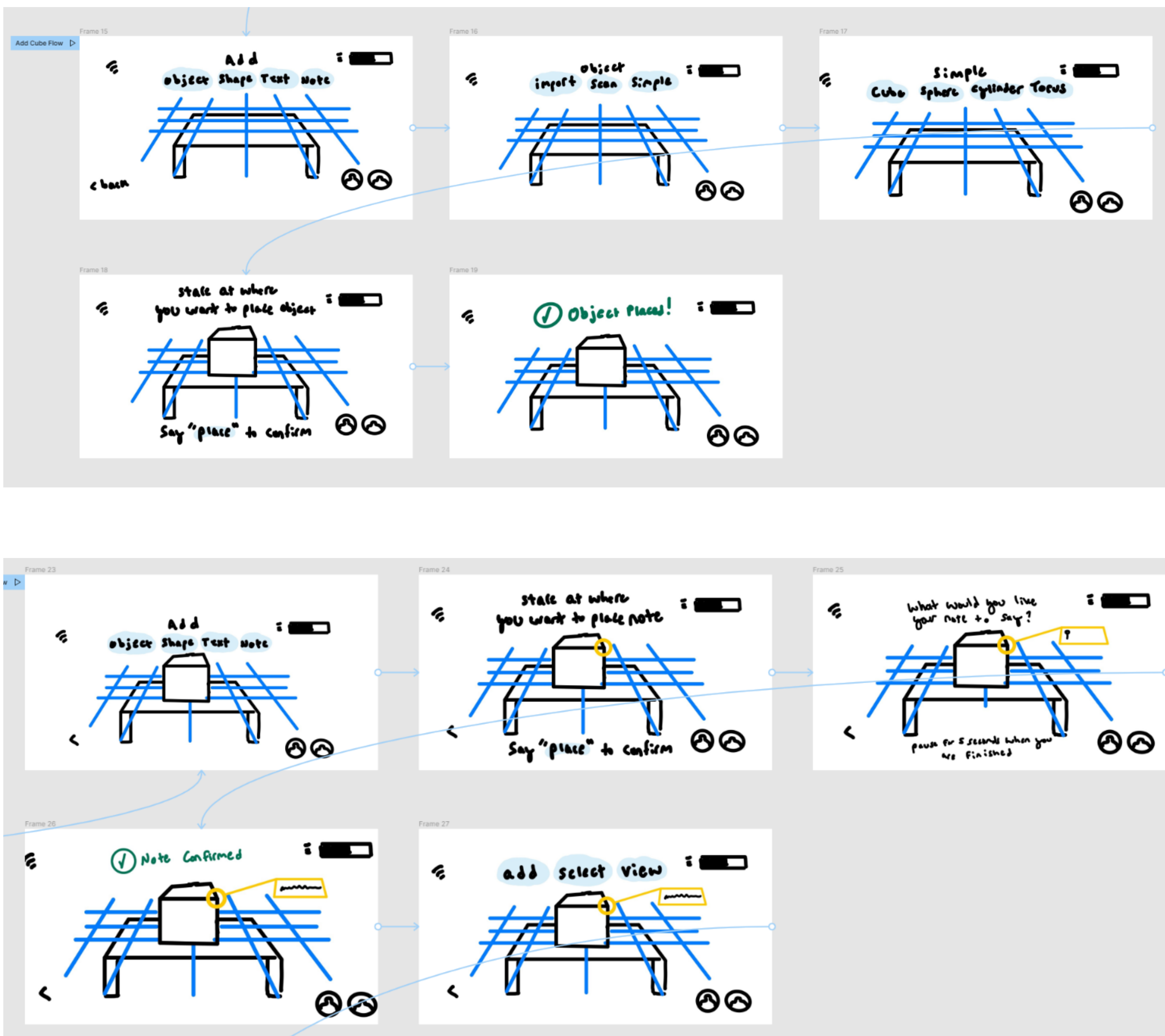


Figure 12: Add and place objects to workspace

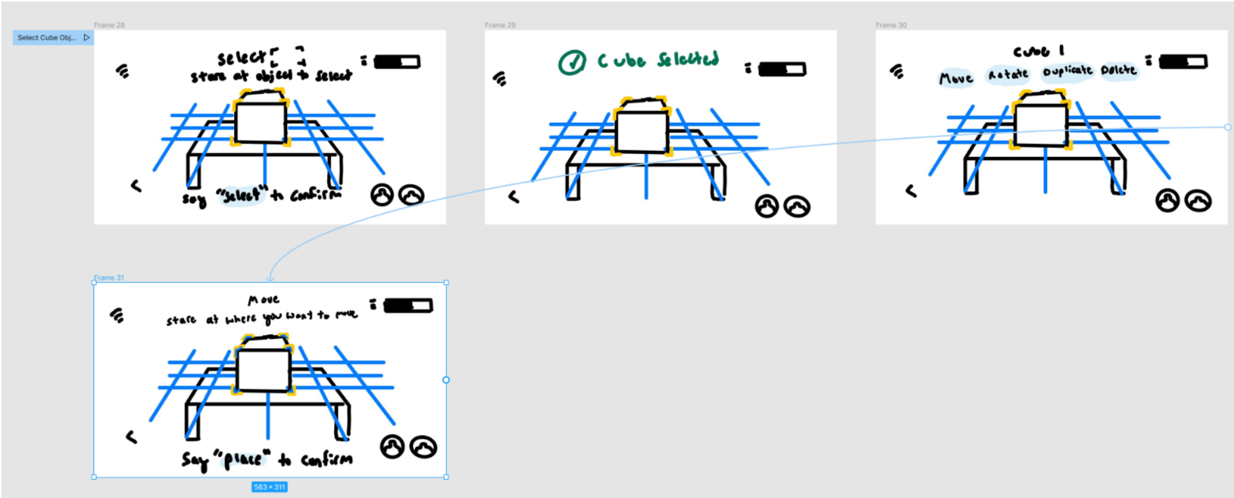


Figure 13: Select and move cube object

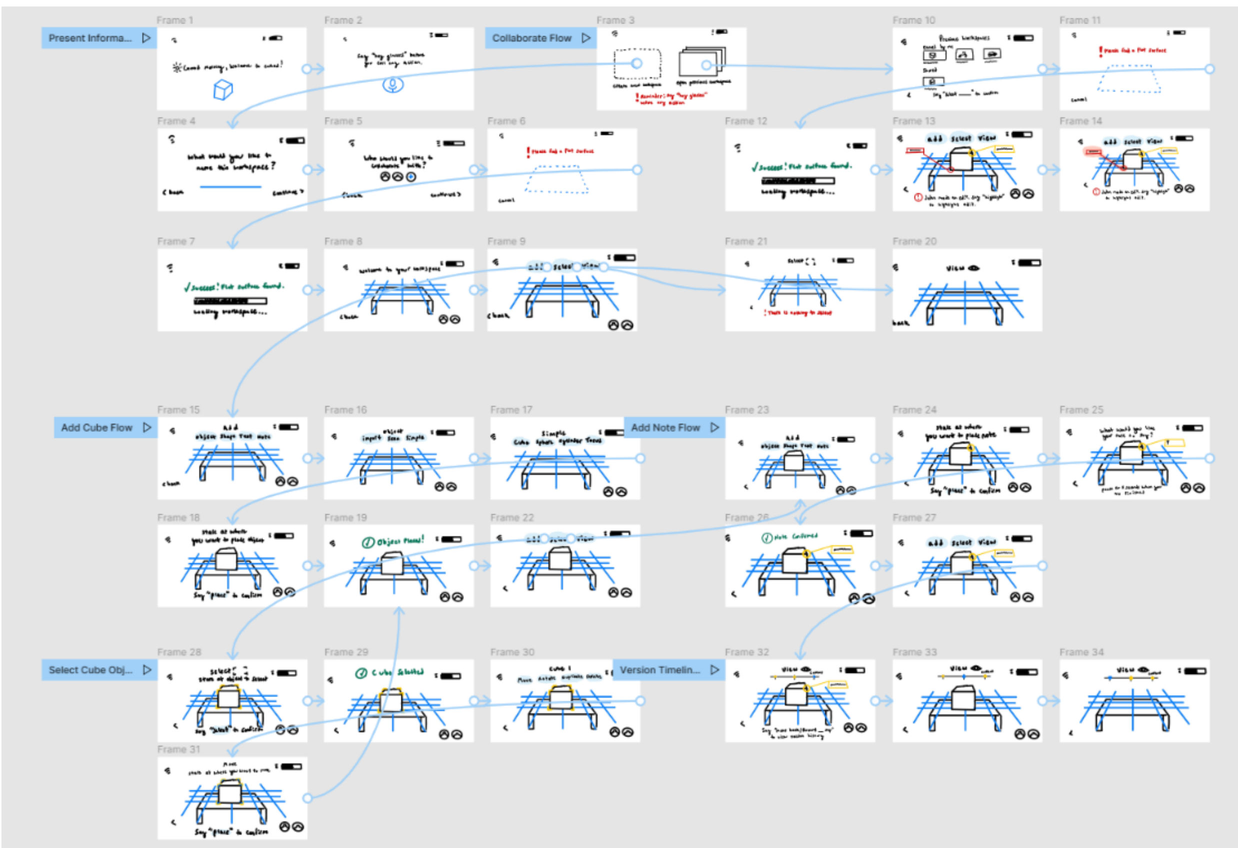


Figure 14: Full low-fi prototype

View on [Figma]

View on [POP]

An Essential Pivot

Our group came up against a problem when transitioning between our low-fi and medium-fi prototypes. Our group realized that our low-fi prototype included technology that would be too difficult for us to implement, so we created and received approval for this pivot proposal instead:

We use an AR realization on a mobile phone to simulate what a user would see through MR glasses (smart glasses). The interactions, such as walking around an object to scan it in 3D or opening a shared workspace by gesture control would now be done by clicking something on screen. We use this approximation because no one in our group has MR glasses or knows how to code with MR glasses, and we expect the actual interface interactions of phone vs glasses to be close approximations.

From Low-Fidelity to Medium-Fidelity

Based on our Low-Fi testing, during which we observed our users as they used our prototype to complete the three tasks (without telling them how to complete the tasks), we came up with various ways to improve our design for the Medium-Fi prototype.

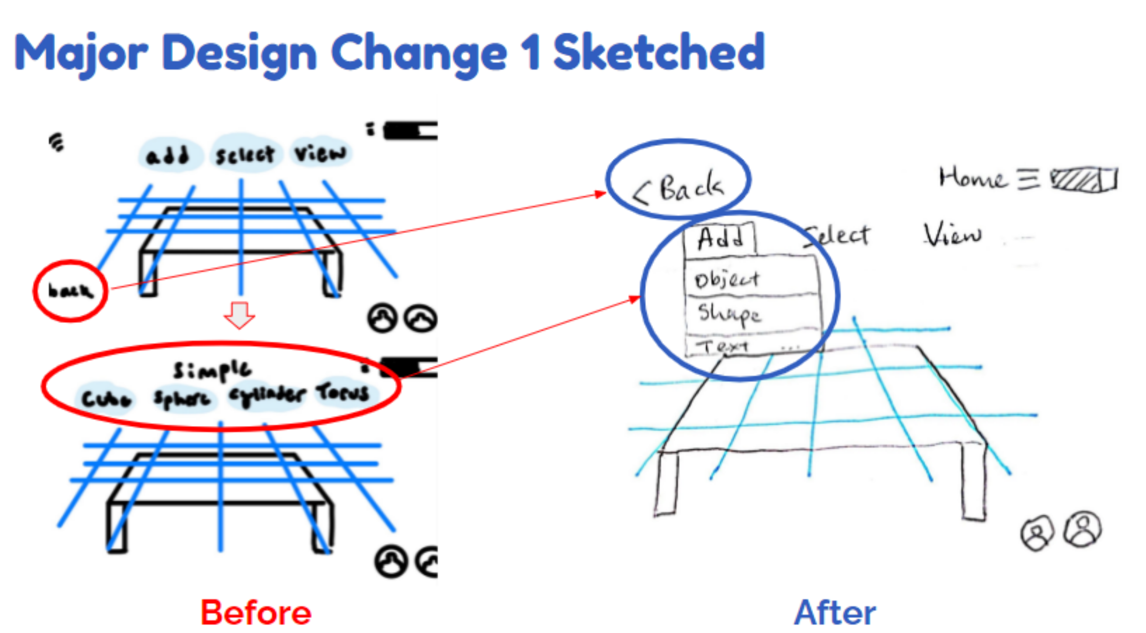


Figure 15: Major Design Change 1: Interface Navigation and Dropdown List

During testing, most users had difficulty with interface navigation. This included finding the back button and, when adding an object, navigating through a second screen to select the type of object. So we moved the “back” button to the top left of the interface to improve the efficiency of navigation and allowed users to select the type of object in more dropdown lists.

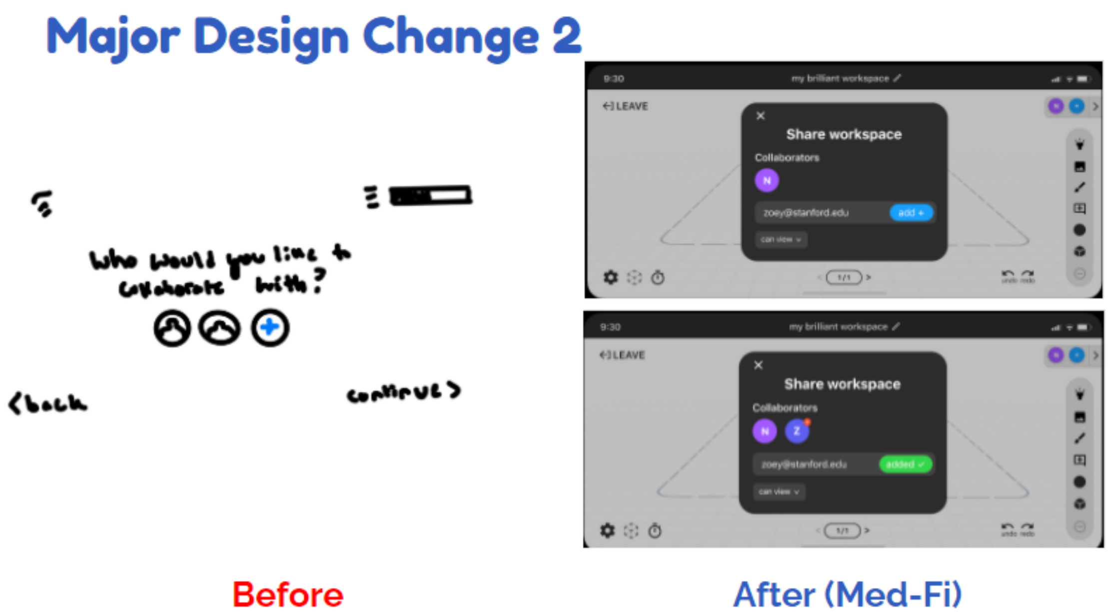


Figure 16: Major Design Change 2: Share workspace

In Low-Fi, users are asked who they would like to collaborate with immediately after creating a new workspace, which makes it unclear how to actually add a collaborator or what your collaborator has access to. Instead, we changed it so that users can add collaborators whenever they’re ready to so that users can draft up a project before asking teammates to edit, view, comment, etc. Also, users can add collaborators with a clear role: as either viewers or as editors.

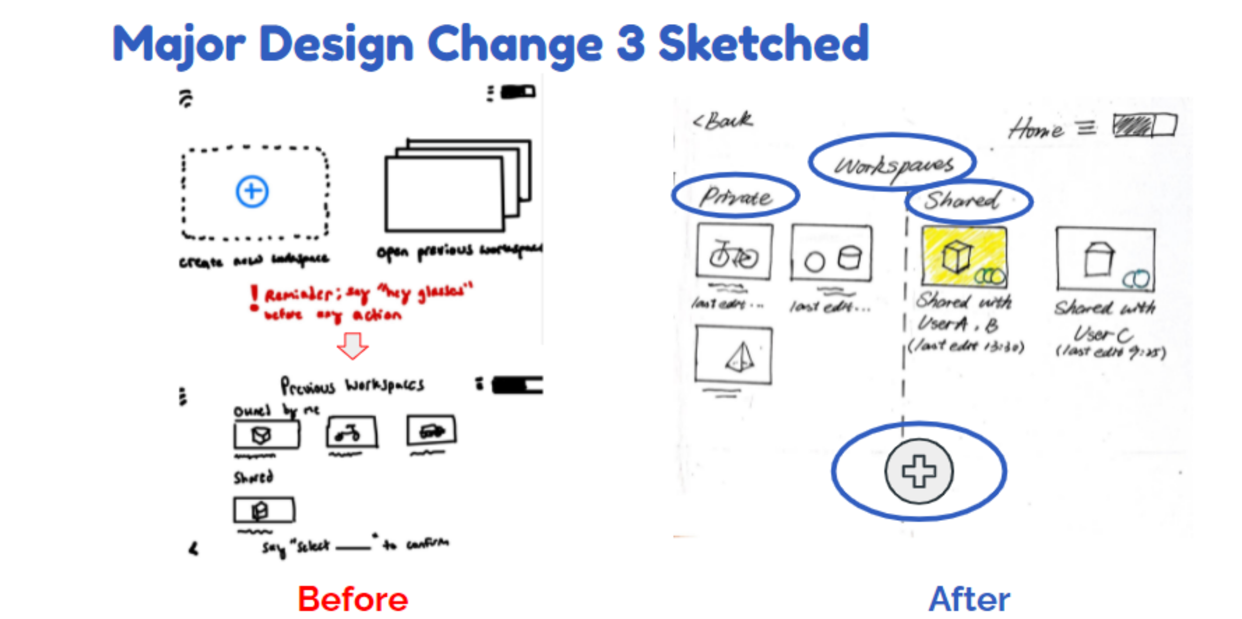


Figure 17: Major Design Change 2: Document Select Page

Lastly, when users previously chose to open a previous workspace instead of creating a new one, they were asked to navigate to a second screen where private and shared workspaces are shown. Now, users are allowed to browse their workspaces right after login, and to create and title a new workspace without having to navigate to another screen.

Medium-Fidelity Prototype

Our medium-fi prototype allowed us to prototype the design of our final product and explicit functionality of the three tasks mentioned previously. With this prototype, we wanted to test our interface changes, user flow, and develop a design language that would persist into our hi-fi prototype. We developed it using Figma as it gave us collaborative capabilities as well as the ability to prototype for a mobile device. Access it [here](#).

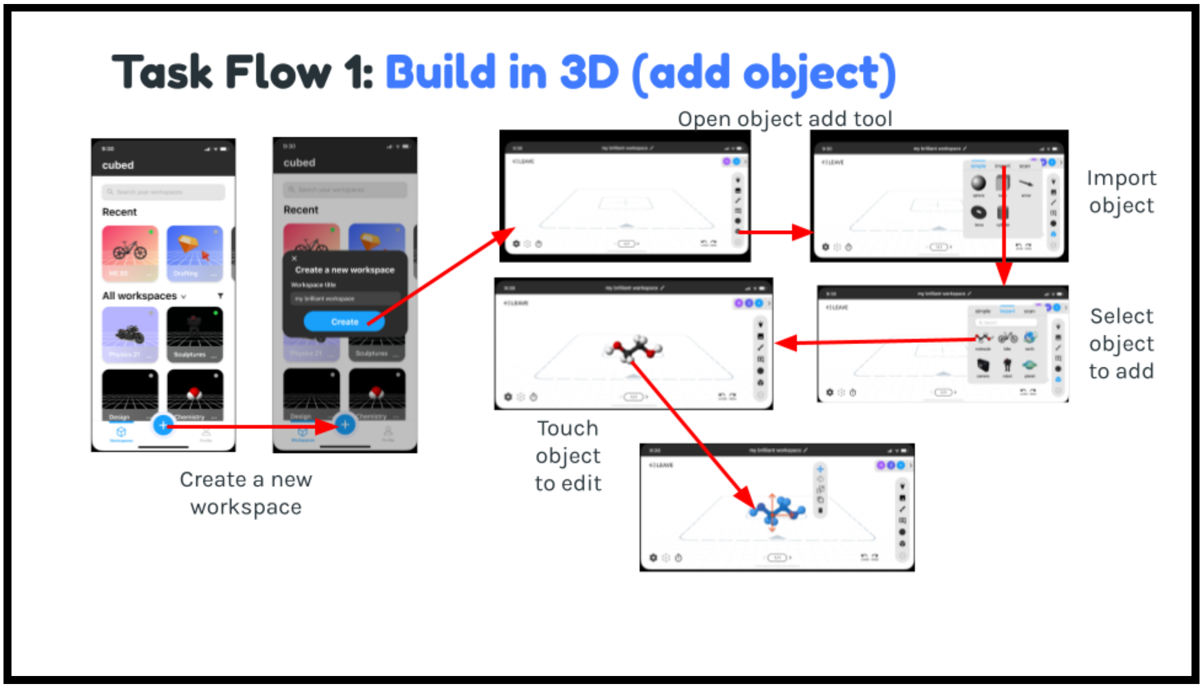


Figure 18: Med-fi task flow 1: add 3D objects.

The first task flow of the medium-fi prototype begins with the user at the document select screen where they're able to select a previous workspace or create a new one. When the user creates a new workspace, they are then guided to naming the workspace. After pressing create, they can enter the 3D environment where they can begin creating and collaborating in 3D.

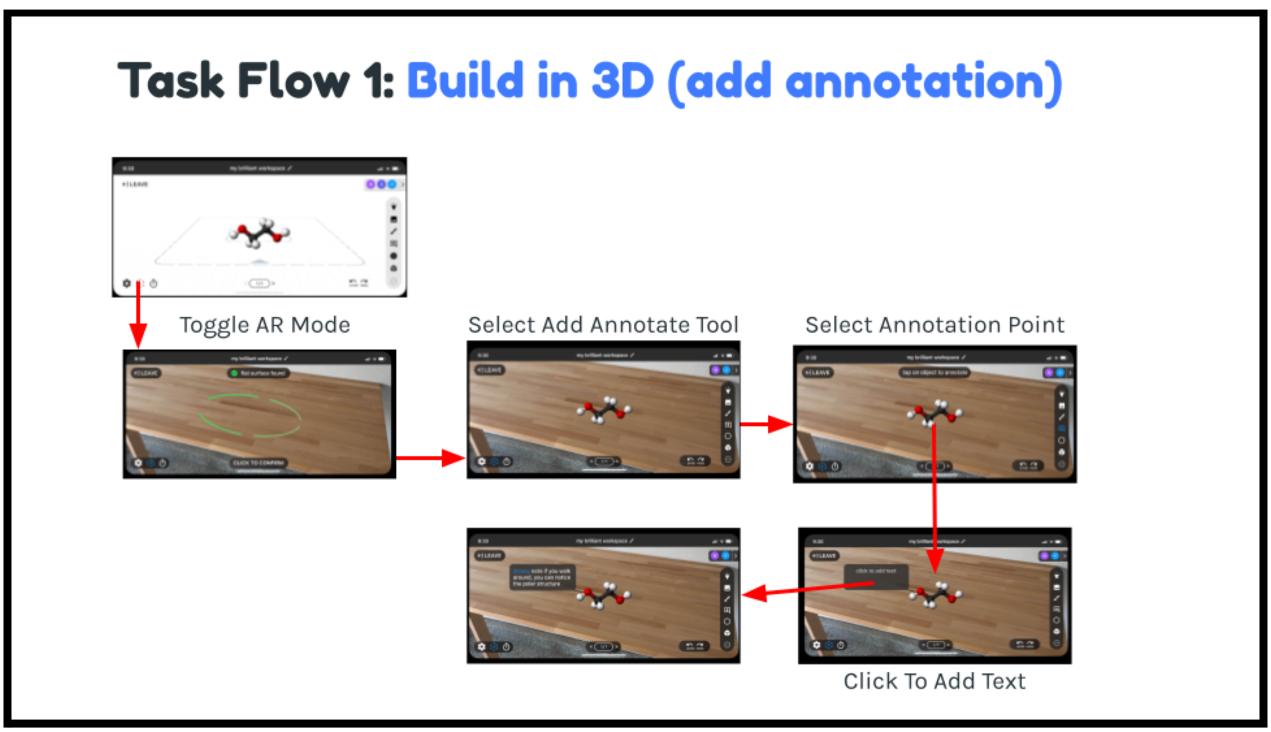


Figure 19: Continuation of task flow 1. Display how to enter AR mode and add annotation.

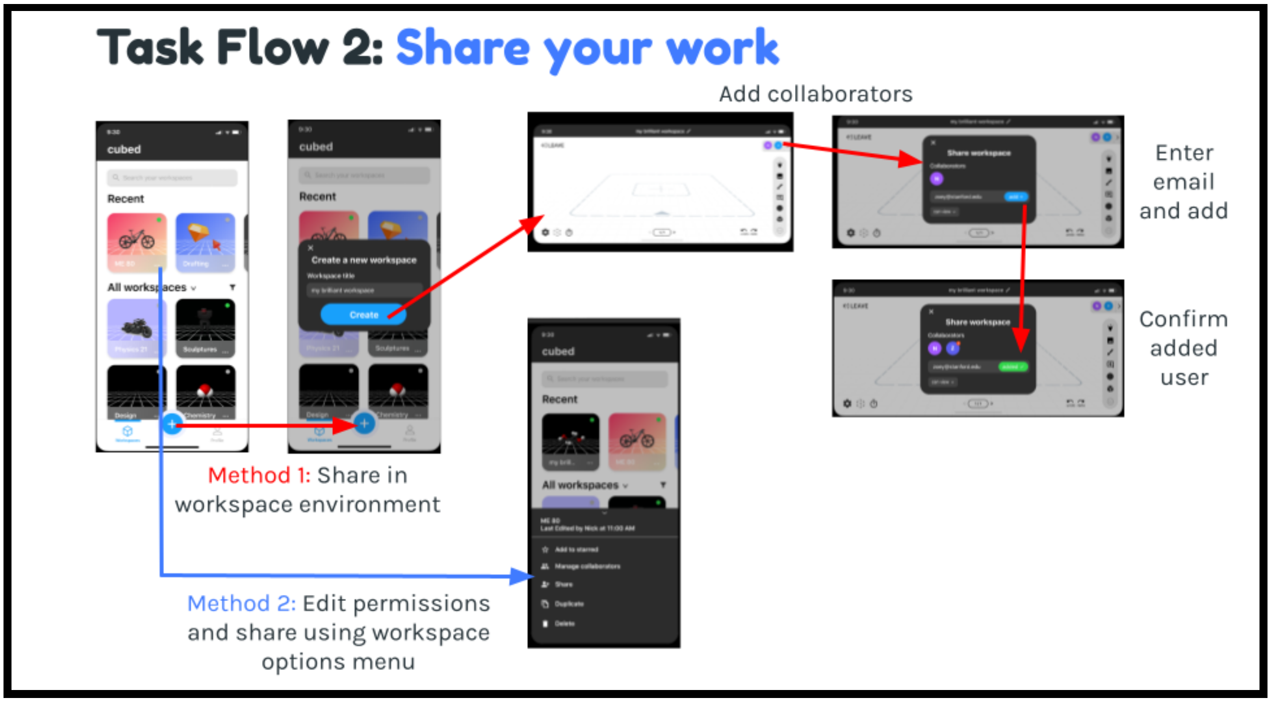


Figure 20: Med-fi task flow 2: share your workspace.

The second task flow shows how the user can share their workspace with another user. In the medium-fi prototype, the user is given two avenues to complete this task: (1) in the document settings on the document select screen and (2) within the 3D environment.

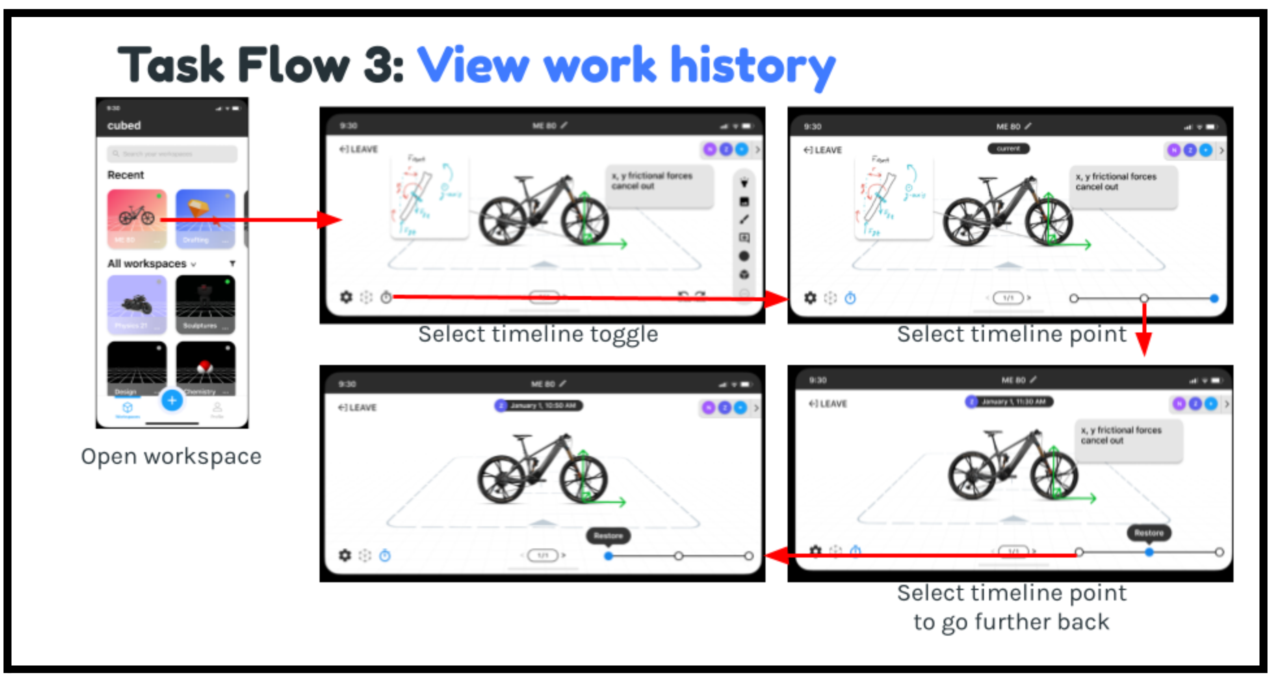


Figure 21: Med-fi task flow 3: view work history.

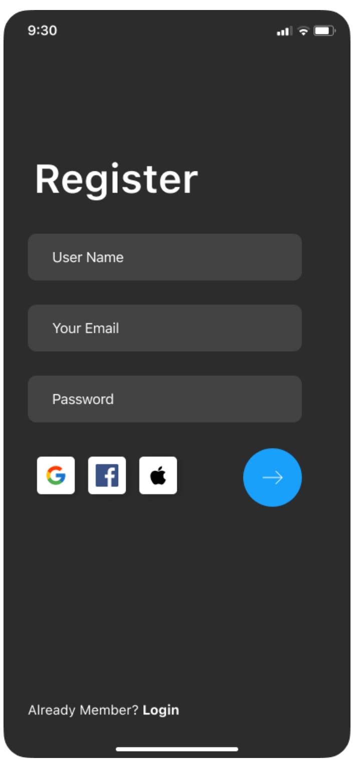
The third task flow shows how the user can view their work history. After opening a previous workspace, the user is able to click the timeline toggle and view their past edits to the workspace. They can then choose to restore that version.

Medium-Fidelity to High-Fidelity: Major Usability Problems Addressed

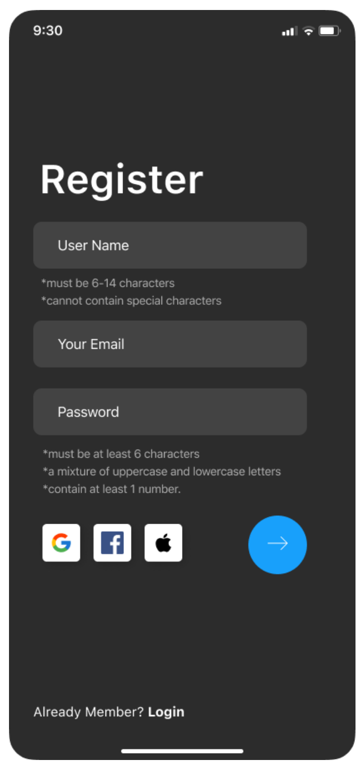
Our hi-fi prototype has addressed the major usability problems identified in the med-fi heuristic evaluation, with all the severity 3 and 4 violations changed as follows:

Problem 1: Sign-in Requirements (H5: Error Prevention)
In the med-fi prototype, the registration screen does not communicate username and password requirements. Users might run into errors if they input strange characters or fail to create a long enough password.

- **Type:** H5: Error Prevention
- **Severity:** 2
- **Fix:** We have added a few lines of text below the username and password input boxes to communicate the specific requirements for appropriate username and password.



Before



After

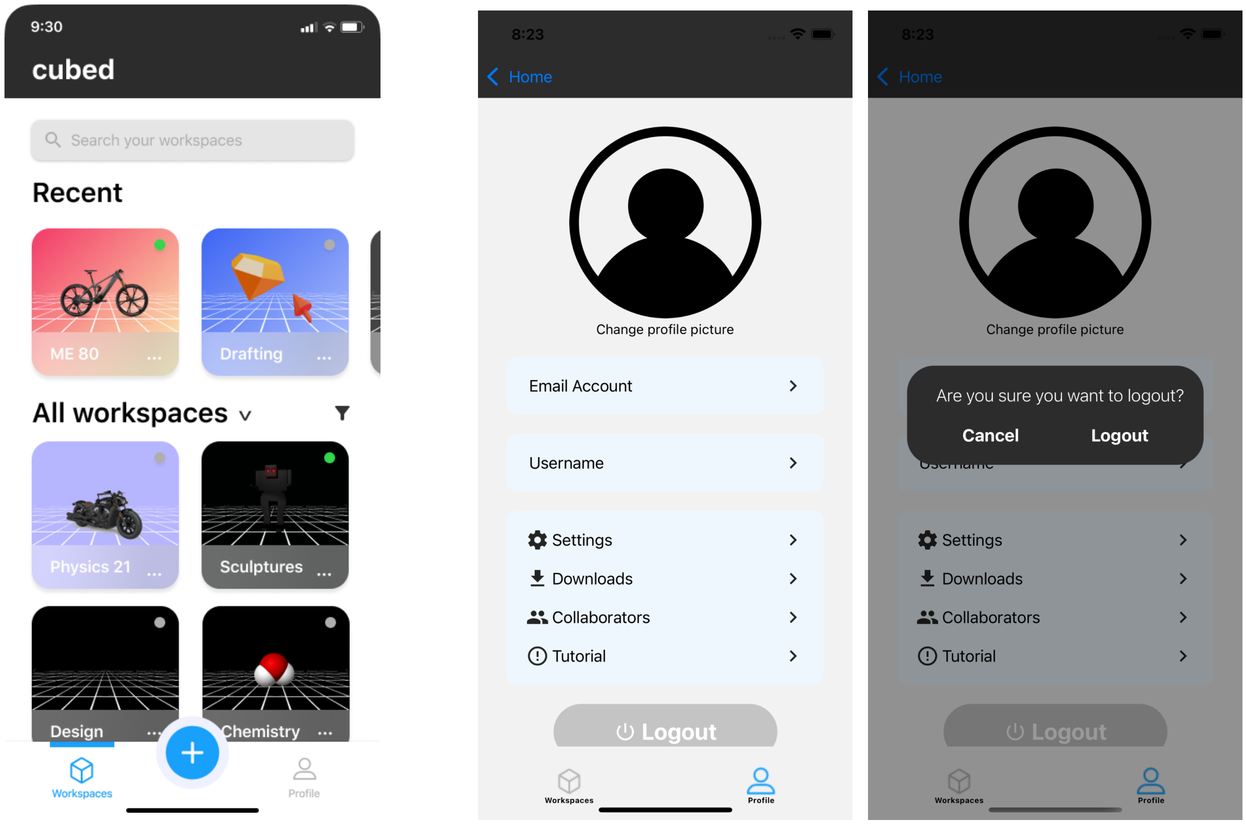
Figure 22: Usability Problem 1 Sign-in Requirement Design Changes

Problem 2: Account Information (H1: Visibility of System Status)
After logging in and reaching the document select screen, there is no information about the account users are signed in with since the profile feature is not enabled. Users would probably want to know details about the account they are signed in with in case they have multiple accounts or want to make sure that personal details in the app like their name are correct.

- **Type:** H1: Visibility of System Status
- **Severity:** 2
- **Fix:** We have built a profile screen where users can access account details, view login information, manage downloads and collaborators.

Problem 3: Multiple User Profiles (H3: User Control & Freedom)
After logging in, there is no way to log back out and reach the login screen again. Users might want to have multiple accounts, but this issue prevents users from being able to access different accounts.

- **Type:** H3: User Control & Freedom
- **Severity:** 3
- **Fix:** We added a logout button on the profile screen for the user to logout the current account or switch to a different account, and added a logout confirmation overlay.



Before (Profile not enabled) After

Figure 23: Usability Problem 2 & 3 Design Changes

Problem 4: Favorite Workspace (H4: Consistency & Standards)

A user is unable to access or filter for their starred/favorite workspaces. This is inconsistent with there being an option to "Add to starred" when you click on the 3 dot icon on a workspace from the home screen.

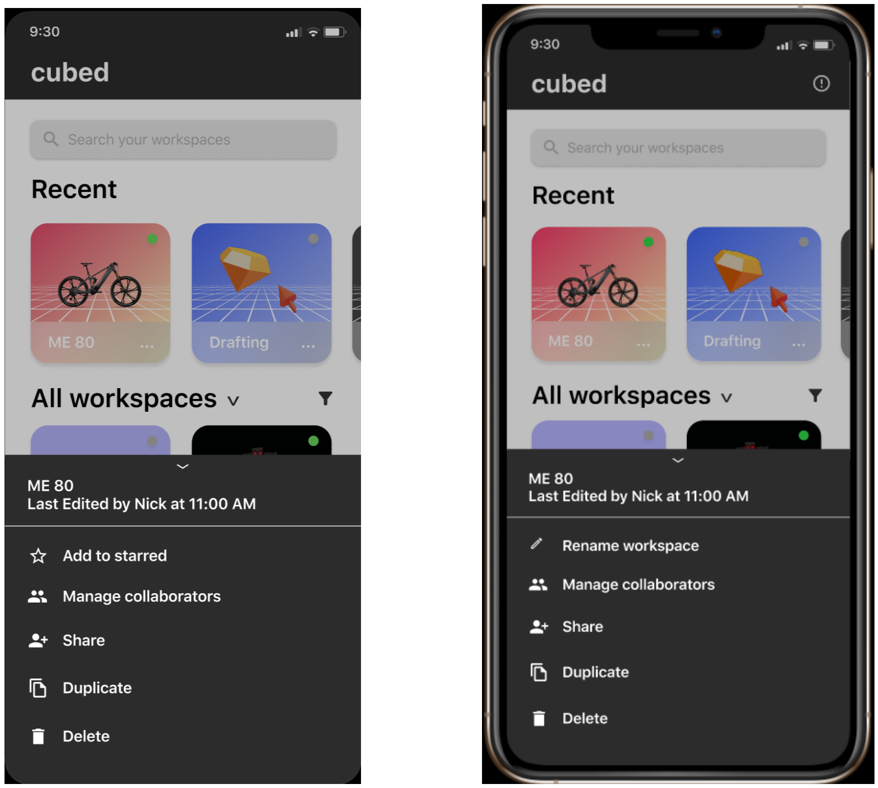
- **Type:** H4: Consistency & Standards
- **Severity:** 3
- **Fix:** We removed the "Add to starred" option in the document setting to simplify the user flow and improve consistency, given that the user already has easy access to the workspaces by filtering "My workspaces" "Shared workspaces" or by searching the workspaces directly.

Problem 5: Rename Workspace (H7: Flexibility & Efficiency)

A user is unable to rename a workspace outside of the 3D editor. This can be annoying for the user if they have to wait for an entire workspace to load before being able to simply change the name of the workspace when they could have done it without waiting.

- **Type:** H7: Flexibility & Efficiency
- **Severity:** 2

- **Fix:** We replaced the “Add to starred” option in the document settings with “Rename workspace” so the user is able to rename workspace in the main page.



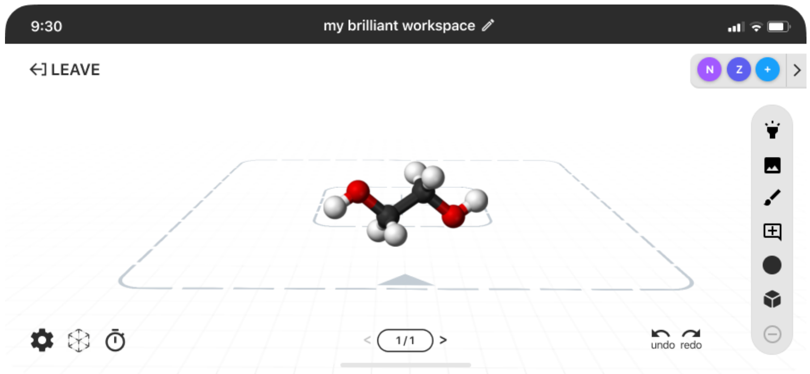
Before After

Figure 24: Usability Problem 4 & 5 Design Changes

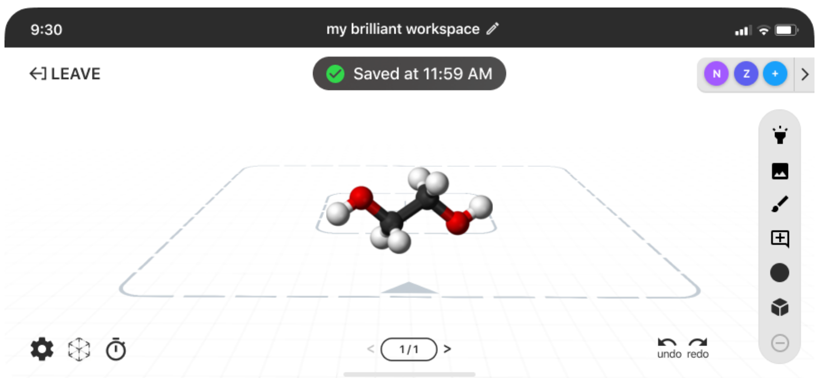
Problem 6: Autosave Indication (H1: Visibility of System Status)

Users could find it knowledgeable and handy to know about the current state of edits, i.e., when the last time a version was saved. A user may unknowingly exit without saving their data so they want to know that all the changes are saved right when they make the changes, which would make them trust the application more.

- **Type:** H1: Visibility of System Status
- **Severity:** 2
- **Fix:** Added a save status indicator to the 3D editor to inform the user when the last time their editing was saved.



Before



After

Figure 25: Usability Problem 6 Design Changes

Problem 7: Tool Documentation (H10: Help & Documentation)

Users are unable to access the tutorial again to understand the functionality of tools.

- **Type:** H10: Help & Documentation
- **Severity:** 3
- **Fix**: Include an option to re-watch the tutorial in the newly built profile page to allow users to re-access the tutorial through the profile page.

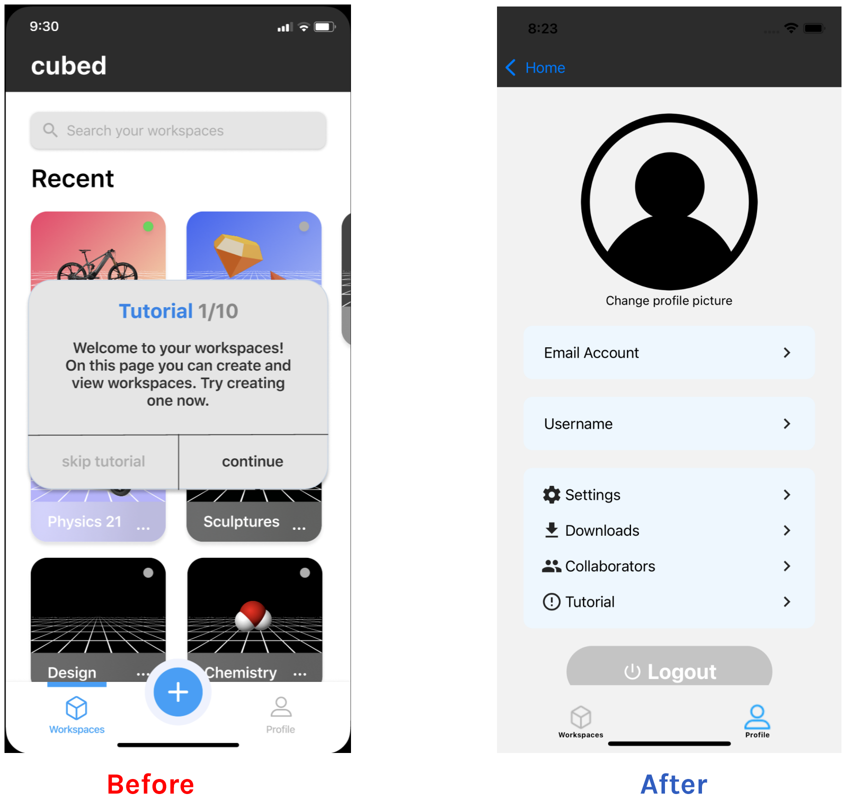


Figure 26: Usability Problem 7 Design Changes

Hi-fi Prototype Task Flow:

Simple Task: Create in 3D

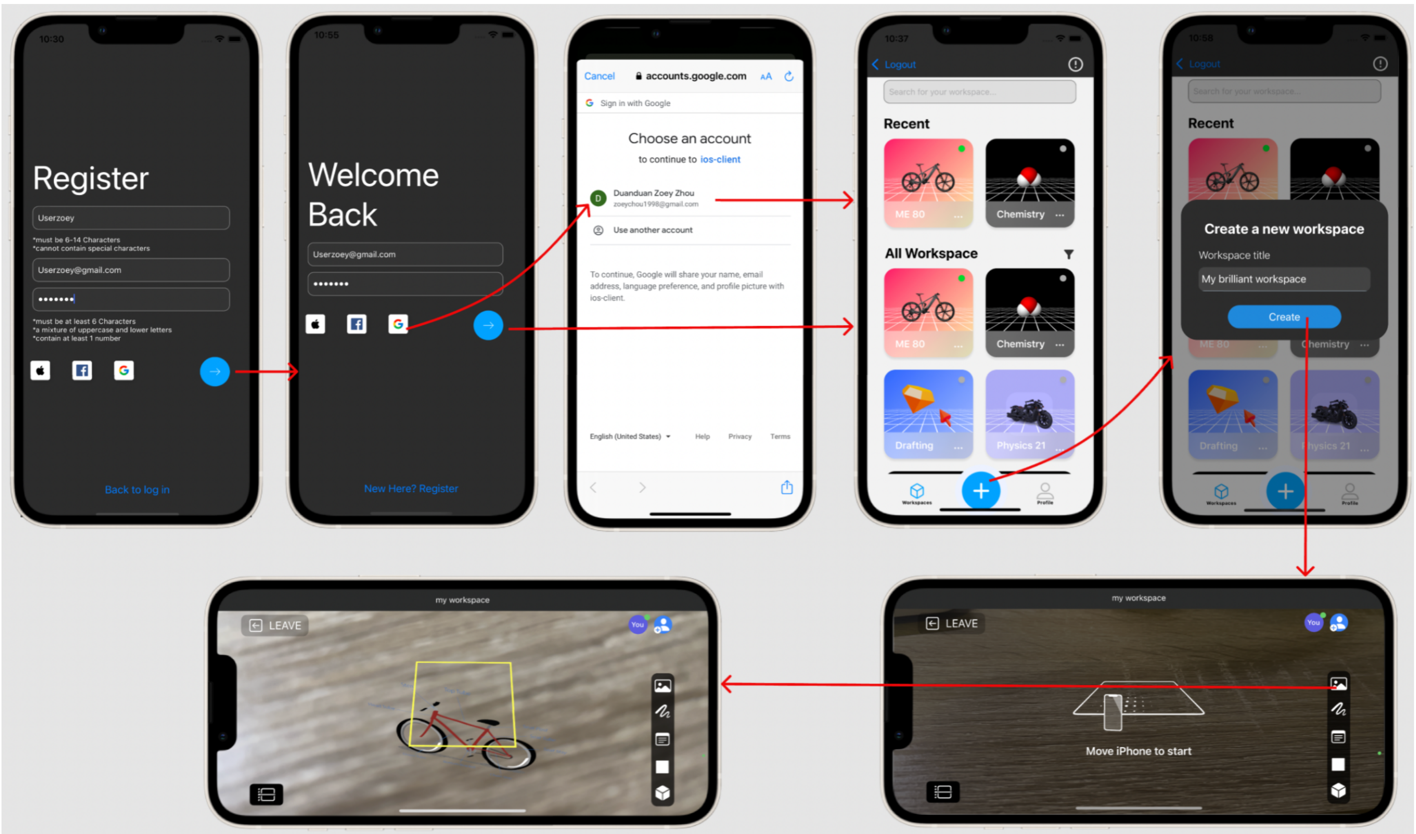


Figure 27: Hi-fi Task Flow 1

In our interactive hi-fi prototype, the user is asked to register and login with a username and email account. Alternatively, the user may choose to login through external Google authentication. For the simple task, the user is able to create in 3D by adding images, objects, sticky notes, annotations and 3d drawings.

Hi-fi Task Flow Walkthrough - Task 2 & 3 (AR)

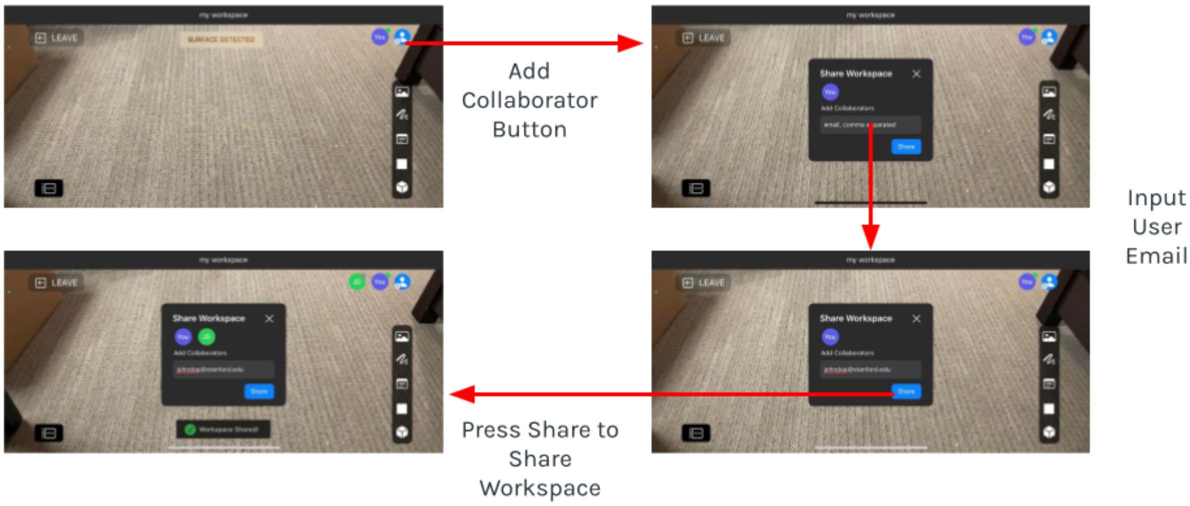


Figure 28: Hi-fi Task Flow 2

Once the user loads the augmented reality editor, they are then allowed to add a collaborator by clicking on the share button in the upper right. Once they enter and confirm a user email, they are granted with verification and a visual indicator that the user is now a part of the workspace. The notification indicator will turn green when they are on the workspace.

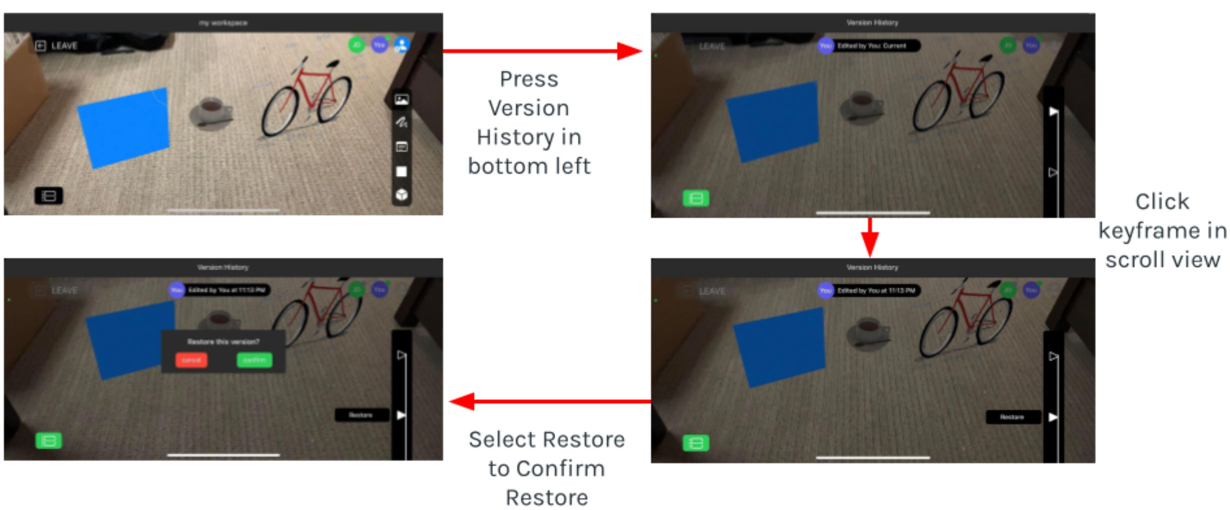
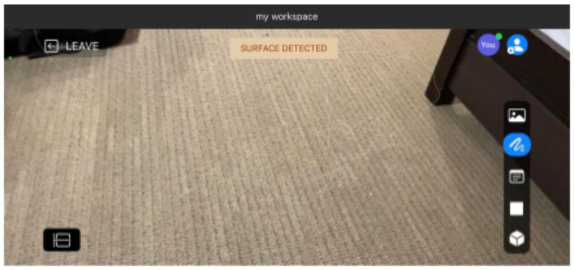


Figure 29: Hi-fi Task Flow 3

After a user has made edits to the workspace such as adding an object or annotation, they can then toggle the version history mode by clicking on the button in the lower left corner. Once they toggle that button, they can then view their past edits with an associated user and time. If they choose to restore that version, they can then do so.



Draw tool: move camera to draw

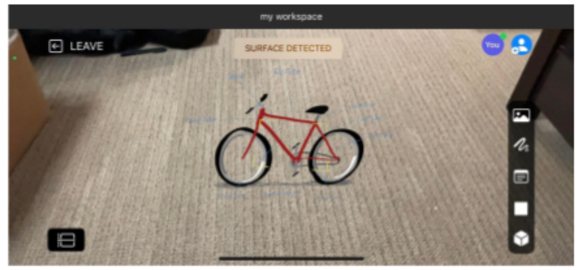


Image tool: add 2D image

Annotate tool: add text annotation

Shape tool: add 2D shape

Figure 30:

Other AR functions enabled on the toolbar. Once added, these entities can be dragged around the space with panning touch gestures.

Values in Design and Mitigation of Conflicts

Finally, it was important that we encoded our values into Cubed. From our previous assignment, the most important values that we encode into Cubed are Constructive Collaboration, Autonomy, and Accessibility.

The value of constructive collaboration is at the core of our design. Cubed allows users to build upon each other's work through a shared workspace, collaborate synchronously and asynchronously, and easily comment on others' work. The add comments and notes feature is central to promoting constructive collaboration among learners, because it allows them to comment on others' work.

Autonomy is also important to our product. There was potentially conflict between collaboration and autonomy in our product, but we mitigated that by allowing users to share their workspaces only after they are ready to. In our design, this translates to not asking users to share the workspace immediately after creating a workspace, but instead afterwards, where the "+" button adds collaborators in AR mode.

Lastly, We are keenly aware of the fact that accessibility is a potential barrier for inexperienced users to use AR products. In our product design, we have enabled version history to allow for easy rollback of mistakes. Accessible features such as flexible imports and a comprehensive tutorial they can go back to at any time also allows users to express their ideas in the way they want to.

Final Prototype Implementation

Tools

We used React Native to build the application framework for the sign-in, document select screen, and profile page. Using React Native in combination with Expo Go allowed us to rapidly test our code and collaborate with one another easily as it allowed for cross-platform development.

Nonetheless, when we attempted to program the augmented reality portion in React Native, we were met with a rude awakening as we found that AR support in React Native was limited. We found brief success with packages such as ViroReact; however, this success was short-lived as we would learn that the test-bed for it was difficult to work with. More importantly, it was not compatible with several React Native packages.

Ultimately, we decided to program in swift using ARKit + Scenekit. This allowed us to quickly test our code on an Apple Device and successfully complete the AR portion. As a result of this choice, however, this also meant that we could not complete cross-platform development.

Wizard of Oz

For the augmented reality editor, we provided the option for the user to add a collaborator to the workspace. While a user was allowed to work through the complete flow of the task, the confirmation and adding the user is purely a visual element and does not enable the user to join and collaborate within the workspace.

Hard-Coded Data

For the document select screen, the size of the icons and images is hard coded. To improve these features we should use dimension functions to read the screen sizes of the devices such that this app will have proper image sizes for multiple devices and platforms.

For the augmented reality editor, we hard-coded the options of the tools such as the image, drawing tool, and 3D object editor. This allowed the user to experiment with these tools but also meant they could not experience the full functionality and breadth of each tool. Furthermore, in the version history screen, we only allowed the user to select one edit backwards as we were not able to implement saving state data past one step.

Summary and Next Steps

Key Learnings

Our two key learnings this quarter were in our initial needfinding interviews and in translating our medium-fidelity prototype to our high-fidelity prototype. We struggled a lot during our initial interviews on best practices, such as asking about what our interviewees know rather than hypotheticals, and what emotions we could extrapolate from just a brief half hour of talking with a stranger. But from continuous practice after incorporating feedback from our TA Taylor and from completing the rigorous Empathy map exercises, we eventually felt more confident in our interviewing abilities. For our medium-fi to hi-fi process, we learned how to translate Figma into a functioning app. We wrote a ton of code and spent hours debugging our AR functionality. This is also the area where we would have most loved to spend more time.

Future Work

If we had more time, we would combine our two separate interfaces into one. We would polish the AR so that it could be toggled on and off with a button instead of our current manual switch, and we would also support even more complex functionality such as scanning something in AR to import it as an editable object. Overall, we were proud of the work we have done this quarter, and if the chance arises, would be excited to explore more ambitious functionality for Cubed!