CS480x-20c: Final Project

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Process Book

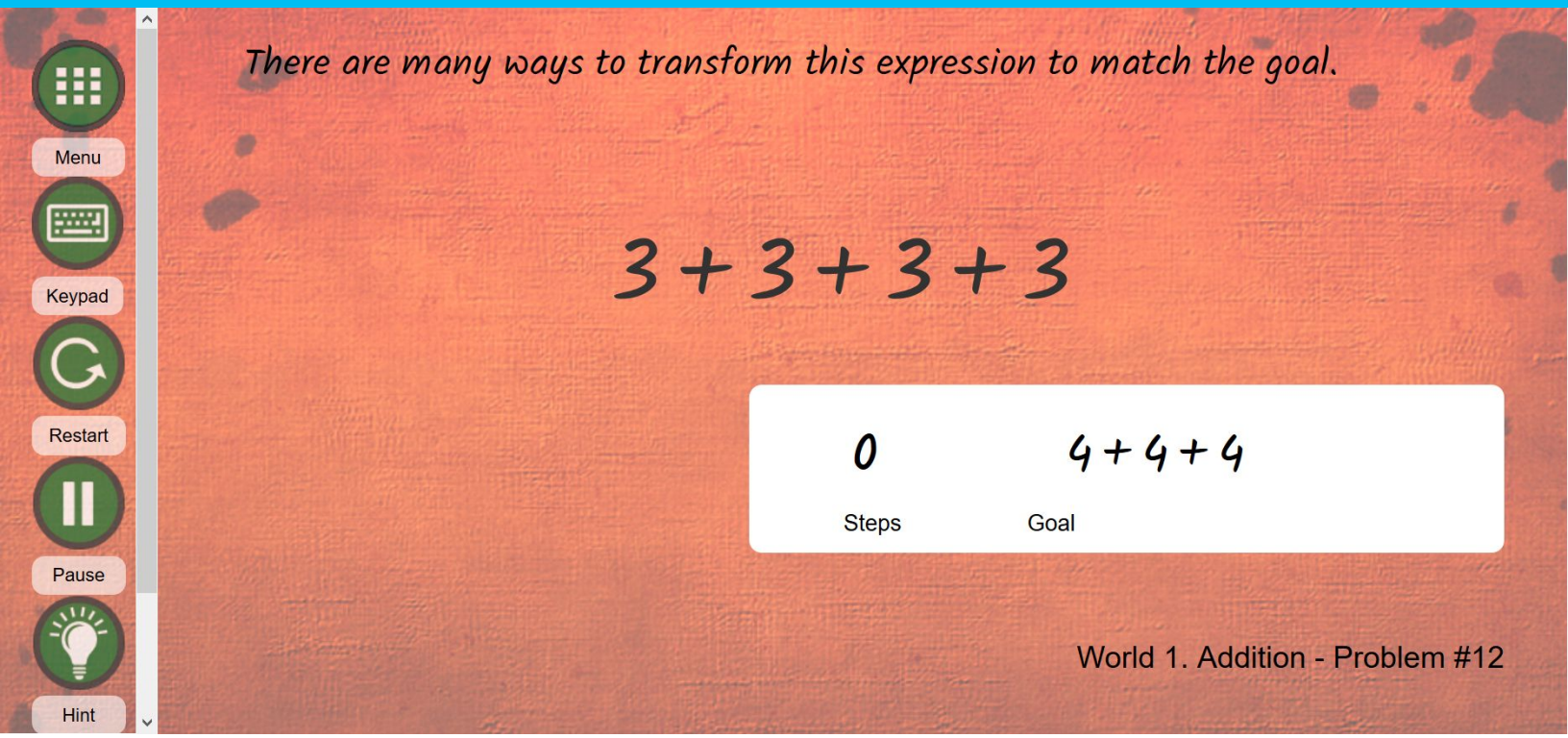
Spring 2020

CS480x-20c: Final Project

Table of Contents

CS480x-20c: Final Project

Introduction

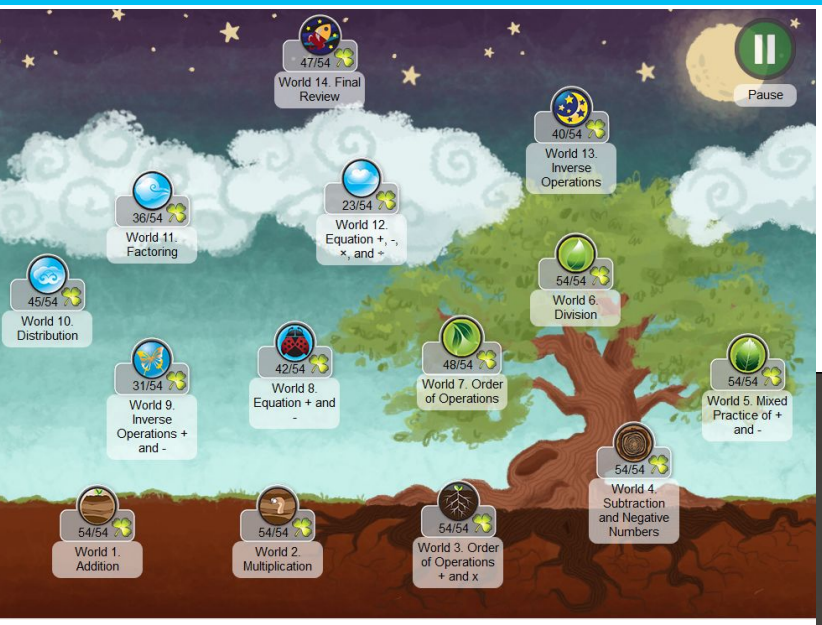


"From Here to There! (FH2T) is a self-paced interactive application that introduces students to mathematical content through discovery-based puzzles. Rather than simply applying procedures by rewriting different expressions, this technology allows students to physically and dynamically interact with algebraic expression elements, providing a potentially powerful source of perceptual-motor experiences," (Ottmar, Landy, Goldstone, & Weitnauer, 2015).

A pilot study was run in late 2019. Log data for a sample of 326 middle school students was collected as students played through the game.

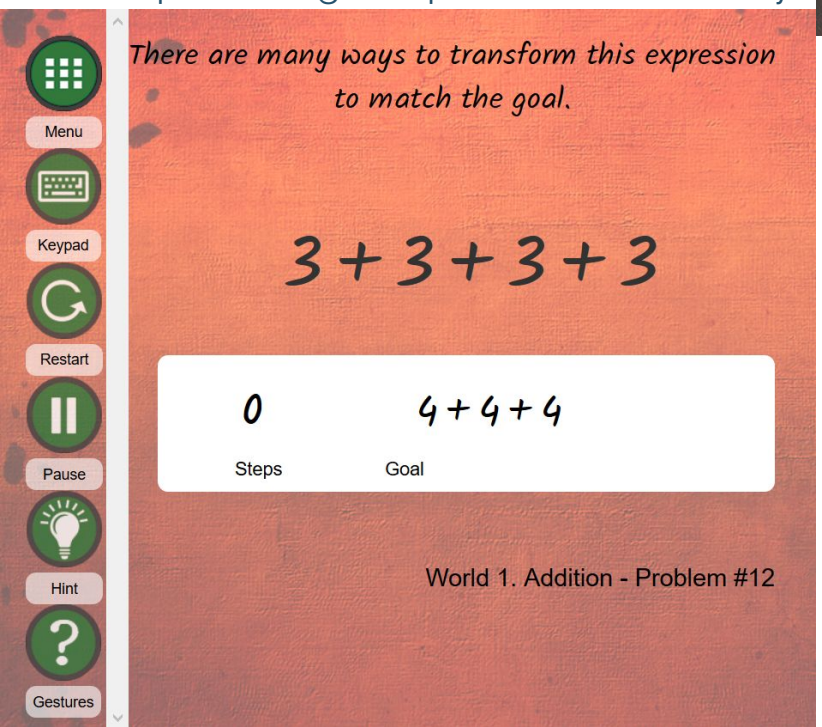
CS480x-20c: Final Project

Introduction



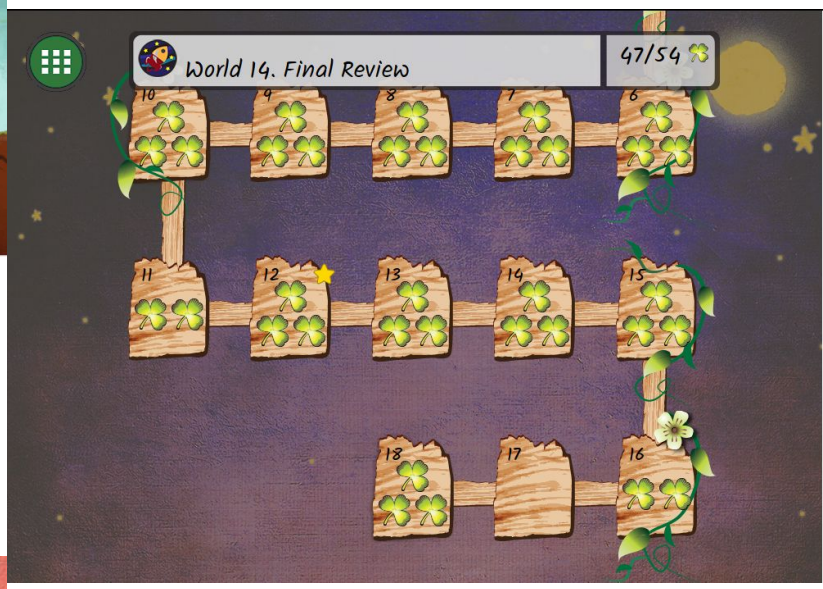
Problem Select Screen

Each problem starts as a blank wood slat, slats with stars ⭐ are training problems. For each problem, students have the opportunity to get a score of up to three clovers🍀 representing completion and efficiency.



World Select Screen

Each world represents a different mathematical focus area. There are 14 total worlds and each world contains 18 problems. Students must complete 14 problems in order to move to the next world.



Problem Goal State Screen

Each problem contains a mathematical expression or equation start state (e.g., 3+3+3+3), a step counter (e.g., 0 Steps), and a goal state (e.g., 4+4+4). The objective is to transform the start state until it matches the goal state.

The selection bar on the left includes a keypad for splitting numbers in specific ways (e.g., 4 → 1+3), a restart button (herein known as a reset, which sets the problem back to the initial state), a hint button, and an index of possible gestures (actions) that can be used.

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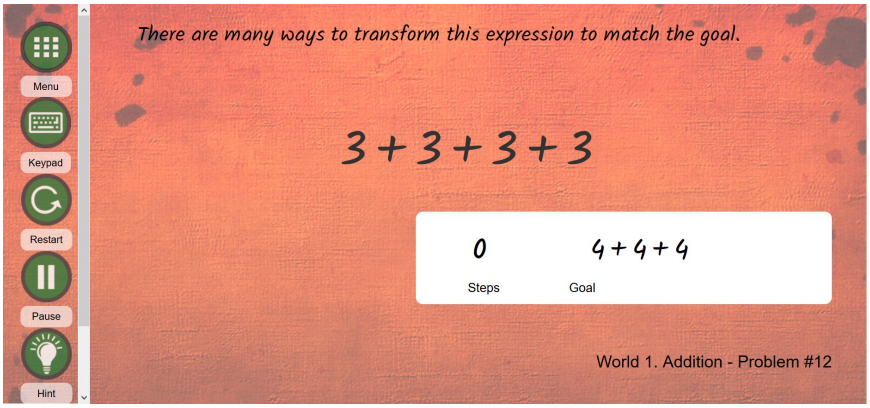
Overview and Motivation



Motivation:

This is the first time that log data has been collected from FH2T with the intent to analyze student patterns. The current method being used to visualize the data has major pitfalls including a large time commitment to generate the visualizations, visualizations are static, and all of the visualizations are displayed as copy-pasted image files in a Google Doc.

Project Goals:

1. Develop a dashboard that facilitates navigation between visualizations for different worlds and problems.
2. Create small multiples of key visualizations that will aid researchers in determining which data to investigate further.
3. Introduce an interactive visualization of first pause time that will filter the small multiples.

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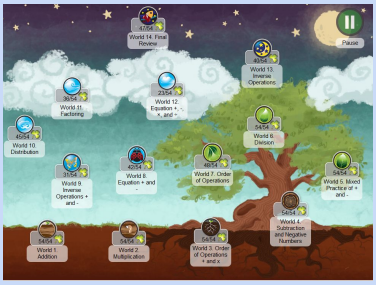
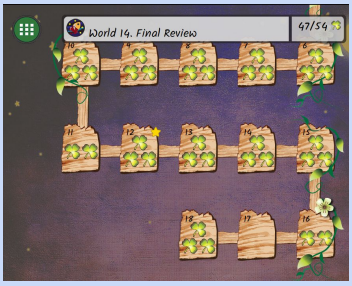
Related Work

Several different sources contributed to the development of this dashboard. While each of these sources are mentioned in their relevant sections an overview is also provided here.



FH2T Website



Provided inspiration for the website layout, also helped to explain the nesting structure & format of the data.

Reflection Visualizations

One of the major themes throughout this course has been how integrating interaction into visualizations can uncover patterns in the data that would have otherwise remained hidden. While no single reflection stands out, the process of creating, viewing, and discussing the reflections throughout the term inspired the use of interactivity in this dashboard.

"Think before you act: Thinking time contributes to math problem-solving efficiency" (submitted to AERA 2020 by Jenny Yun-Chen Chan) was the conceptual basis for the development of this dashboard and was a major contributing factor in the development of the design questions that we sought to answer.

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Questions

What questions are you trying to answer?

Exploratory Questions:

- What is the nature of the problem-level log data that has been collected?
- What variables can provide novel insights?
- What variables are of interest to researchers?

Visualization Questions

- In what format(s) should we display the data?
- How can we interconnect the data?

Evolution of Questions & New Questions We Considered

- How do we restructure the data to account for the fact that some of the exploratory graphs are at the problem level and some are at the world level?
- How do we structure the website so that we can include both world-level visualizations and problem-level visualizations while still making the distinction between the two obvious?
- How do we signal to the user that the bar under the density plot triggers the scatter plots to update so that they only include the selected values?

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Data Source

Log data for a sample of 326 middle school students was collected as students played through FH2T as part of a larger IES Study. The raw data was collected at the interaction level before being aggregated to the problem level by Jieun Lee (one of Erin Ottmar's Postdocs) using R.

The full, problem-level aggregated dataset contains 48 variables for 211 problems (out of a total of 252 possible problems). The eight major categories of variables in the aggregated file include: identifiers, completion, resets/retries, score, time, steps, efficiency, and errors.

For the purposes of designing this dashboard we simplified down to five variables: User ID, Pause Time Percent, Total Time, Efficiency, and Total Number of Errors. In order to do that there was a substantial amount of data manipulation to get the data reduced and in the correct format. Data manipulation was done in SPSS and Google Sheets. Specific variable information is on the next page.

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Data Source

For the purposes of designing this dashboard we simplified down to five variables:

User ID is the assigned ID to blind the data.

Pause Time Percent is the percentage of the total time that the user spent viewing the problem before doing anything to the problem.

Total Time is the total amount of time (including pause time) that the user spent working on the problem.

Efficiency is calculated as the minimum number of moves needed to complete the problem divided by the total number of moves that the user actually made the first time they solved the problem.

Total Number of Errors is the total count of specific errors that the user made while solving the problems. Specific errors include when users typed in a non-equivalent expression using the keypad, when the user tried to perform an action that was incorrect (e.g., adding 2+2a), or when the user tried to incorrectly commute terms.

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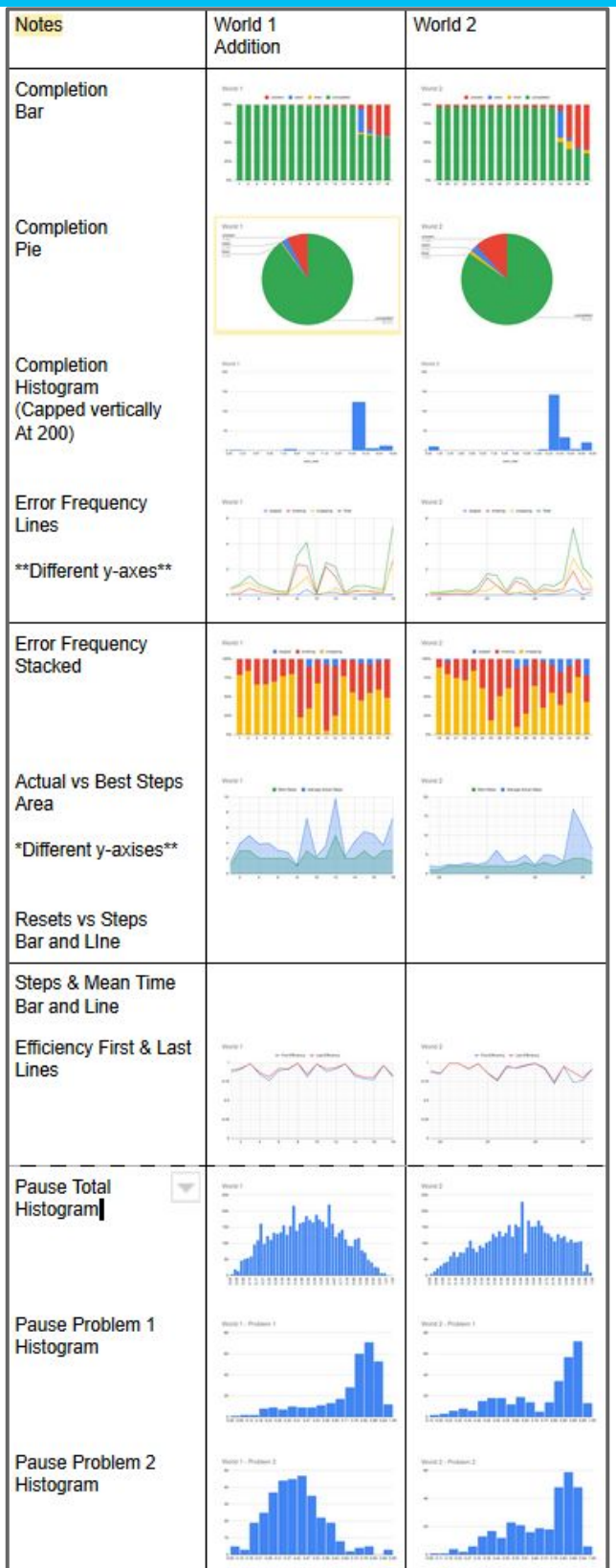
Exploratory Data Analysis

Initial visualizations were created in Google Sheets, then copy-pasted into a Google Doc.

These initial visualizations revealed several main insights:

1. Variable calculations were wrong for best steps (and efficiency (calculated from it))
2. Students display different patterns of pause time for different problems
3. On average, the majority of the sample did not complete the optional problems (14 - 18)
4. Efficiency was fairly consistent across problems, however, there were key problems that caused drops in efficiency
5. The drops in efficiency do not necessarily coincide with the problems that had a lot of errors



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Exploratory Data Analysis

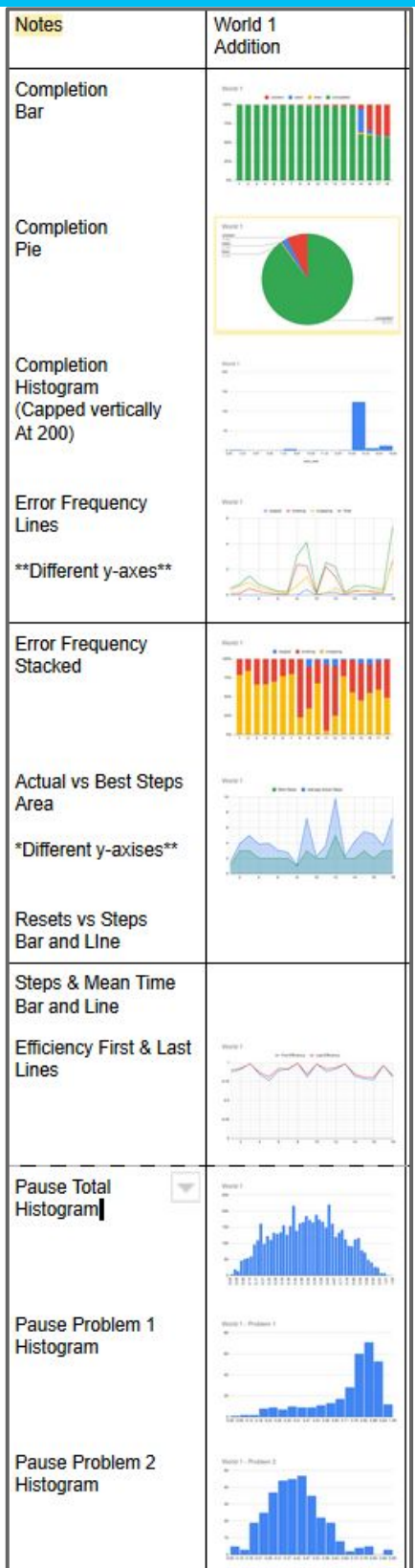
How did these insights inform your design?

First, variable calculations were corrected.

Next, we started to narrow down the list of visualizations to only include variables that had the possibility to provide novel insights.

Deciding which visualizations were of particular interest to the researchers was a large part of this step. We decided to structure our selections based off of an article currently being developed by Jenny Yun-Chen Chan. The article, titled "Think before you act: Thinking time contributes to math problem-solving efficiency" (submitted to AERA, 2020), uncovered evidence to suggest that students who had a longer proportion of pause time solved problems with higher efficiency in fewer steps than students with a shorter proportion of pause time.

Finally, we speculated that students with higher pause time may display differences in key variables than students with lower pause time. This informed our decision to add a filter for the data based on a selected range of pause times.



CS480x-20c: Final Project

Design Evolution: Preface

For the design process for this project we utilized the Five Design Sheet methodology (for more information see fds.design; Roberts, Headleand, & Ritsos, 2016); for our five design sheets, see appendix A.

In this section we highlight core design elements that we explored, organizing them by content as follows:

Page layout

- Navigational features
- Stylistic decisions
- Usability

Visualizations

- Individual visualizations
- Focus on making them interactable

Prototyping

- Focused sketches done while discussing how the flow of the final product will be and which visualizations to include

Final Concept Sketches

- A clean summary of what was decided at the end of the prototyping phase along with notes about specific features

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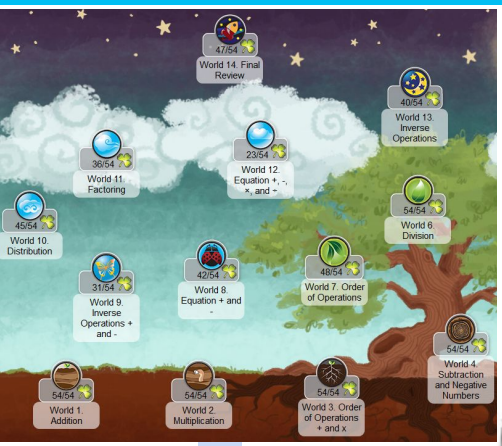
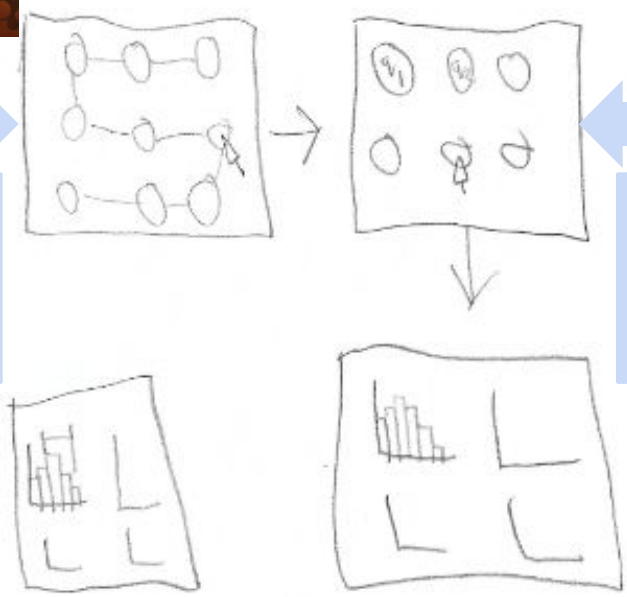
Design Evolution: Page Layout





Vis prototype world selection screen styled after FH2T world selection screen.

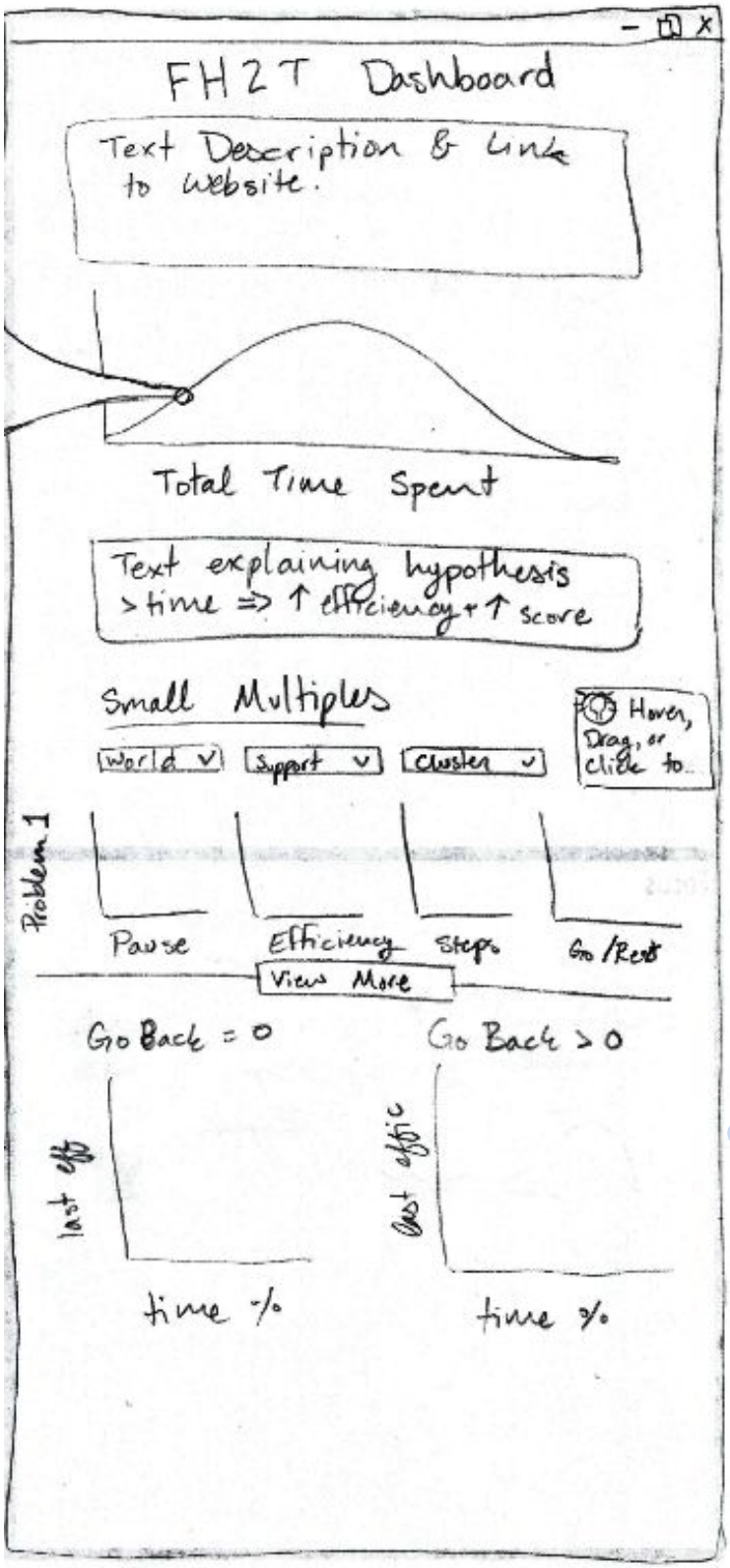
Vis prototype problem selection screen styled after FH2T problem selection screen.

During the first phase of prototyping a model was developed where the vis webpage would be modeled after the existing FH2T world selection and problem selection windows.

While this is both stylistically appealing and utilizes the familiarity of the existing layout, we decided against this approach because the amount of time it would take to navigate between worlds would limit the ease of usability.

CS480x-20c: Final Project

Design Evolution: Page Layout



Another prototype of the page layout was styled using a scrollytelling technique. In this prototype the vis would start with a description of the project, then display key findings along with a brief description of the existing research, followed by a collapsable list of interactable small multiples, and ending with a couple of static scatter plots.

This approach emphasizes the story of the data rather than the investigation of the data. Because our aim was to develop a tool for researchers to use, we decided against this approach.

These prototype documents are being repurposed for use describing the data collected from this project to educators who may be interested in having their students participate.

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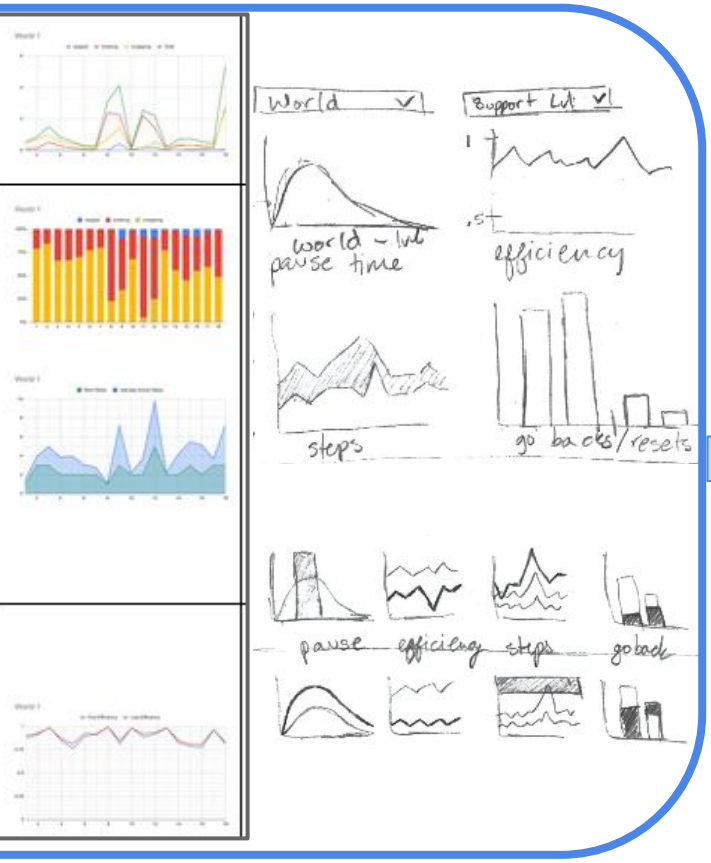
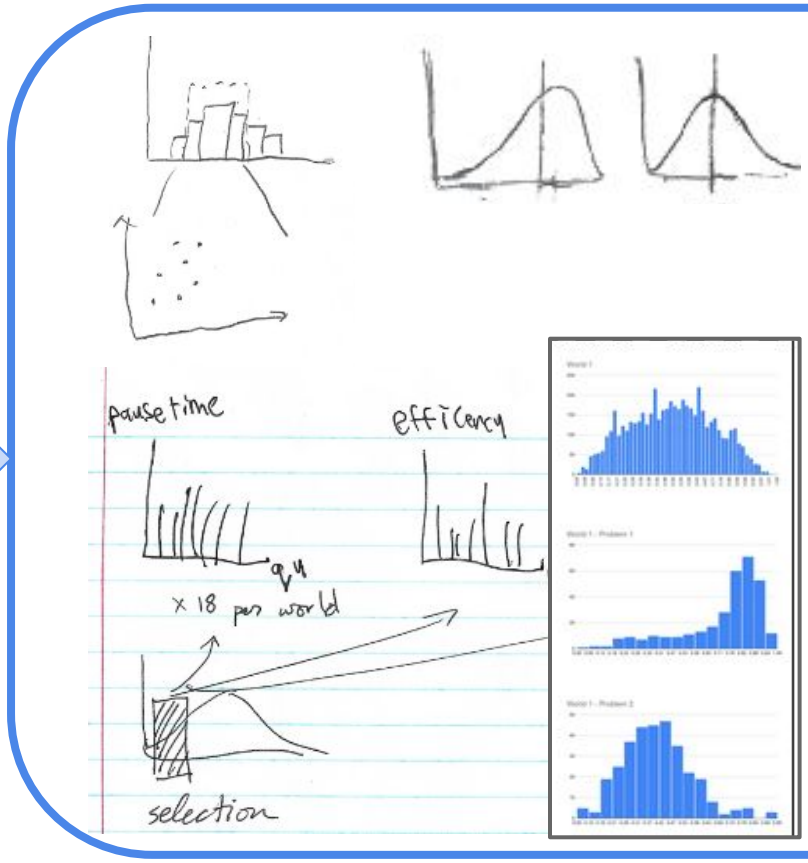
Design Evolution: Visualizations





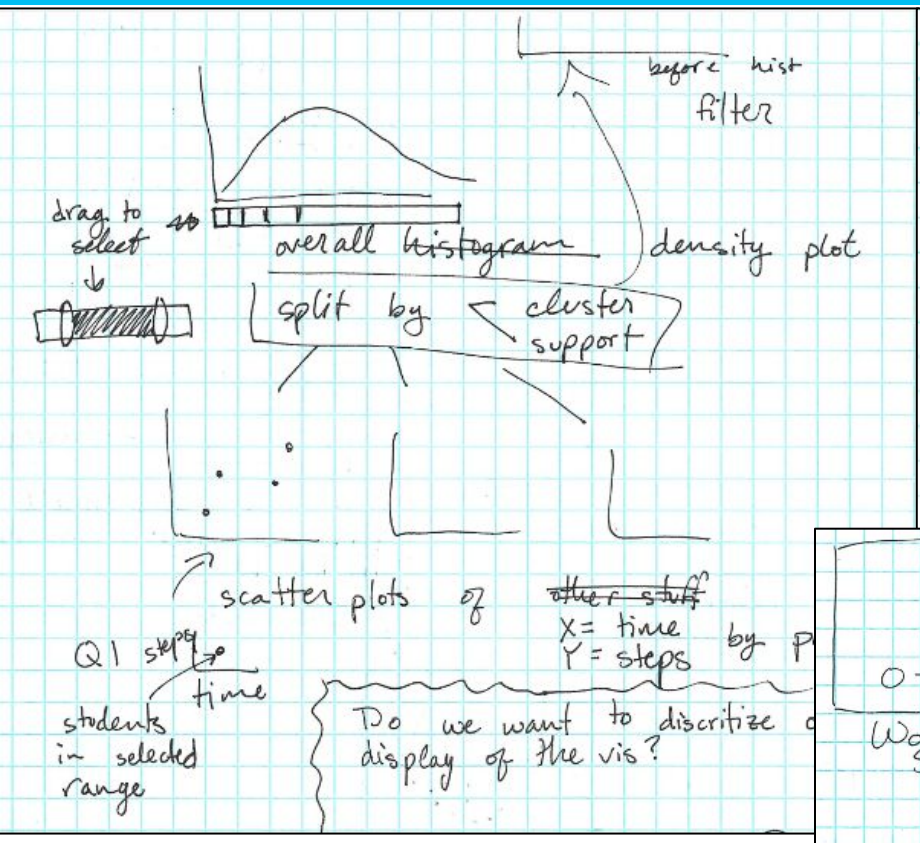
What are the different visualizations you considered?

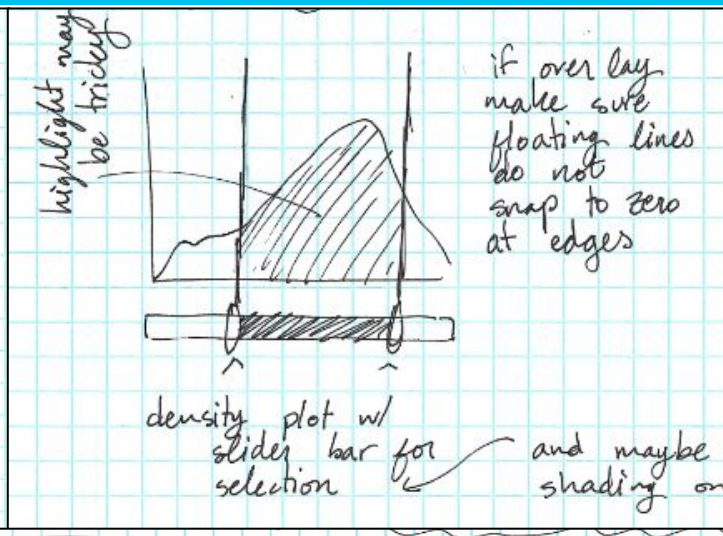
The initial, exploratory visualizations done in Google Sheets presented a wide variety of possible options for visualizing the data. These followed the design principles outlined in Visualization Analysis and Design (Munzner, 2014), however, there were two main points that caused us to move away from using them:

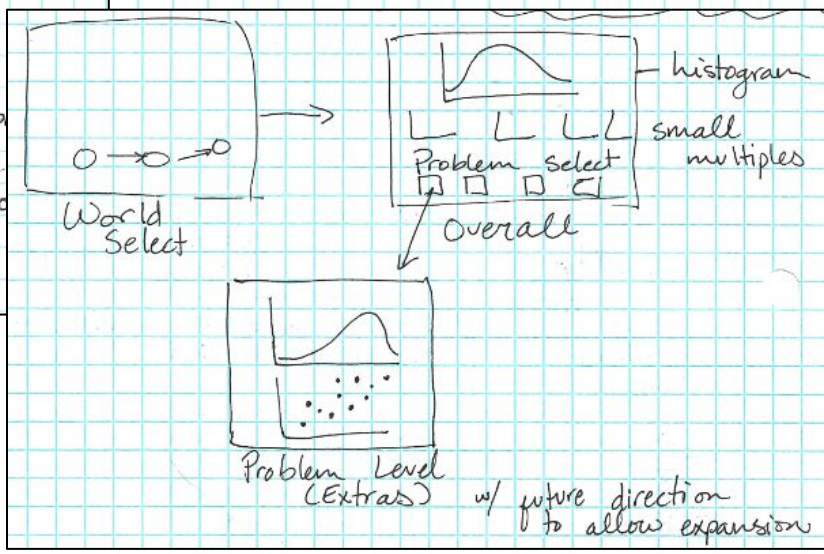
1. The structure of the data lends itself better to density plots than other types
2. More interesting relationships can be investigated when the coordinated views are scatterplots

CS480x-20c: Final Project

Design Evolution: Prototyping







The next series of design prototypes were focused on developing a plan for how the different visualizations would be connected. We decided that the main focus would be a density plot of pause time with the ability to filter three scatter plots of pause time and

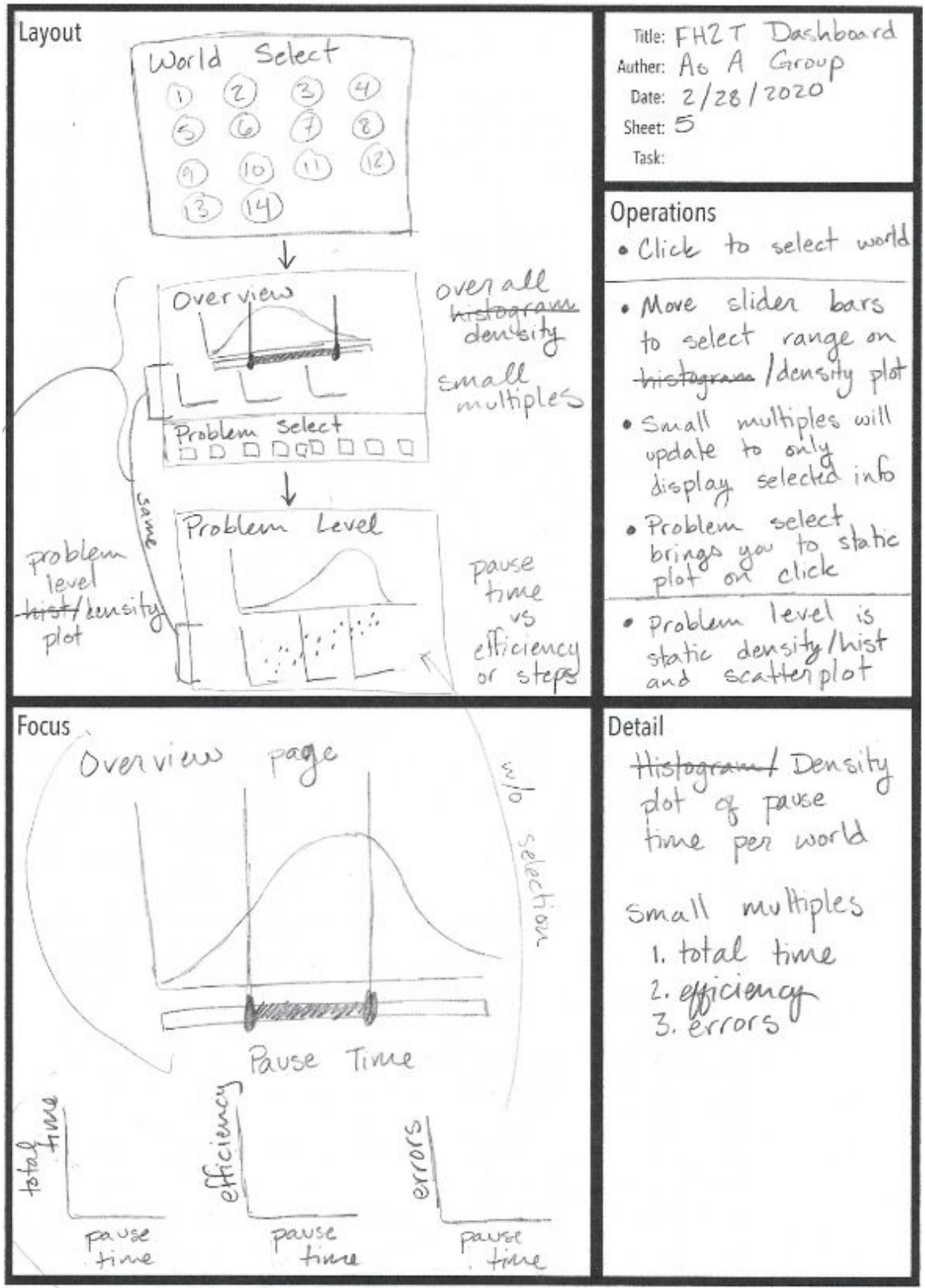
1. Total Time,
2. Efficiency Percent, and
3. Total Number of Errors

Did you deviate from your proposal?

After many iterations the resulting design did match the proposal to a fair degree. The final design does include connected interactivity between charts and displays different aspects of the data.

CS480x-20c: Final Project

Design Evolution: Final Concept Sketch



Presented here is the fifth sheet of our Five Design Sheet process.

The overall layout displays the process of moving from the world select screen (top), to a selected world which includes an overview and a problem selection option (middle), to the specific images for the selected problem. The overview focuses on the ability to filter the scatter plots using the the sliders on the density plot.

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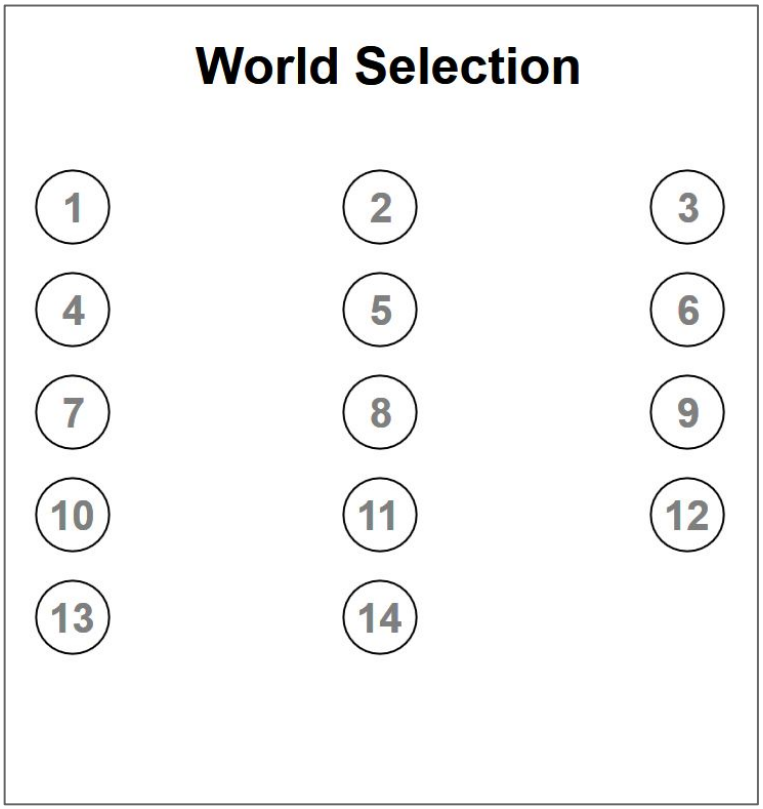
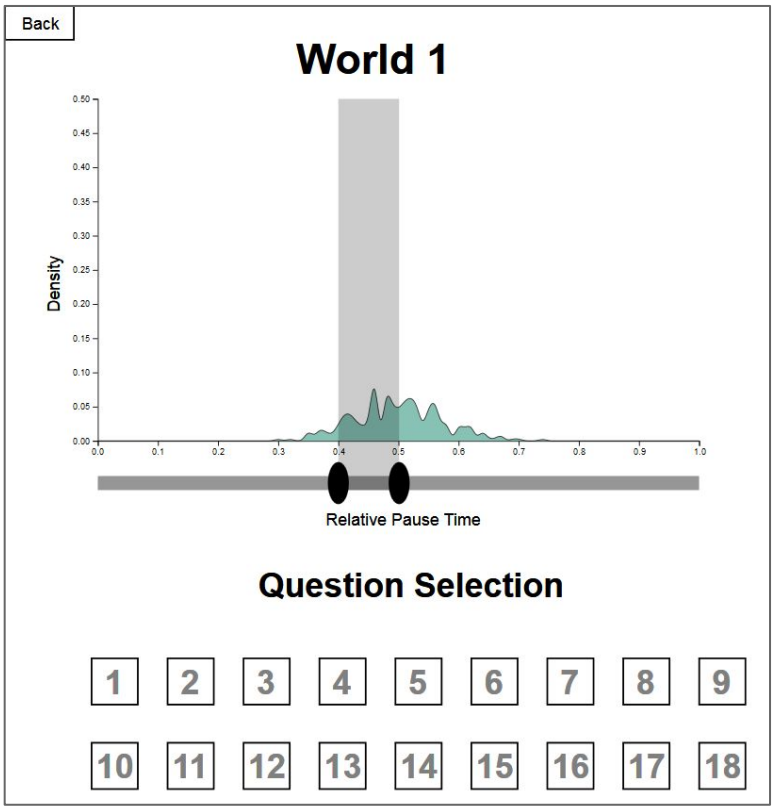
Implementation

The World Selection Screen



World Screen with Question Selection Bar



One of our focus areas while designing this dashboard was creating an intuitive, user-friendly interface where the user can easily select which world, and which question to visualize. We achieved this by creating world selection circles that mimic the world selection circles on the FH2T website. Furthermore, problem selection rectangles in each world allow the user to navigate between problem-specific visualizations in each world.

The dashboard can be accessed at: https://wbahm.github.io/final/combined/

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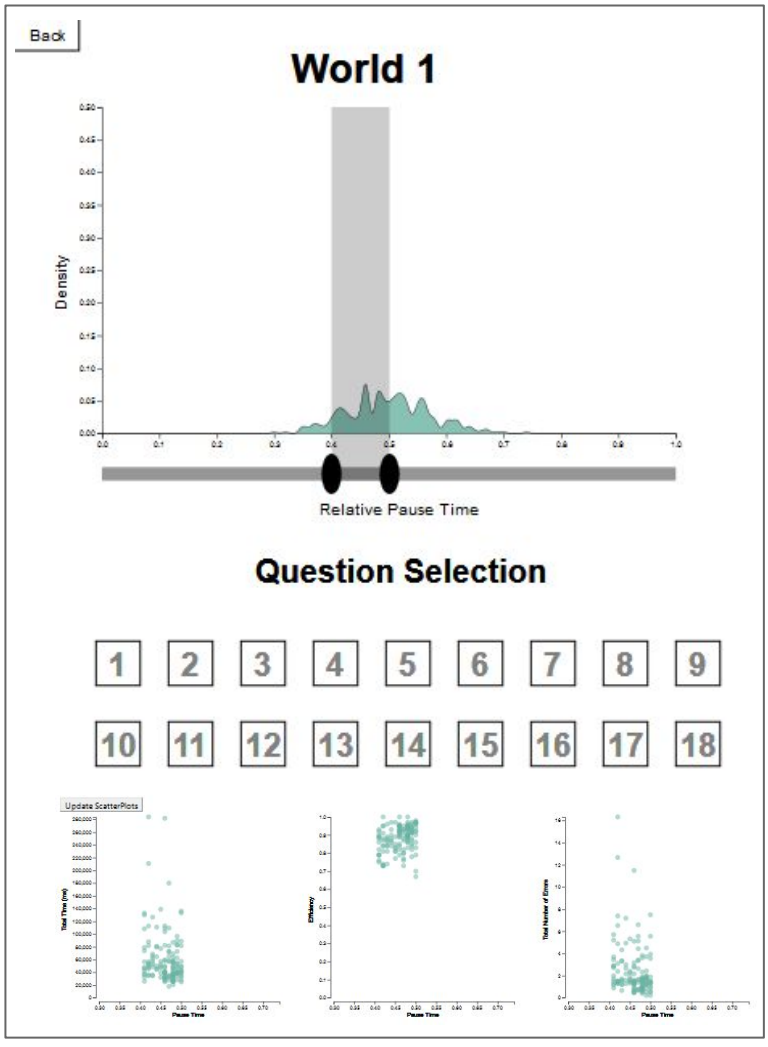
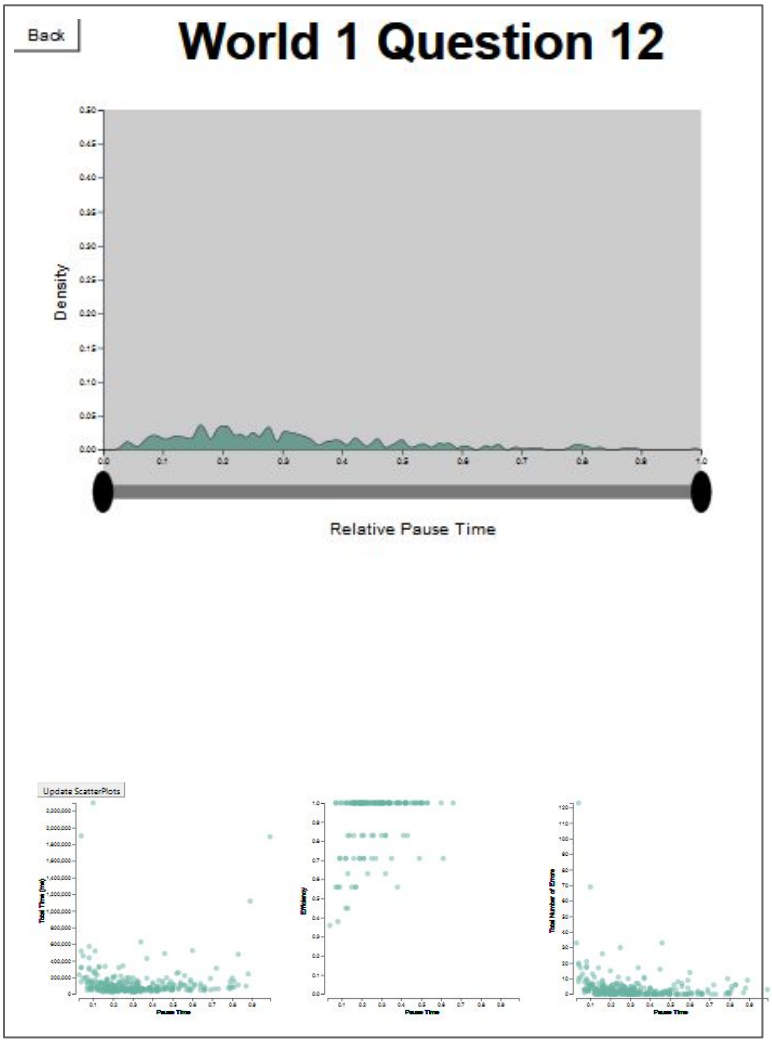
Implementation

As far as the data we are visualizing, since the client was particularly interested in how the pause time affected 3 other factors, We created a density graphs for pause time, and 3 small multiple scatter plots to display pause time on the x axis and the 3 other measurements on the y axis. We also wanted to allow the user to select a range of pause times and only display those points on the scatter plots. We accomplished this through a slider bar and a shaded region that helps visualize the selected area.



Overview After Selecting a World



Specific Information for a Selected Problem

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Evaluation & Future Directions

For the purposes of evaluating this dashboard as a research tool we examined World 1: Question 12 which has been shown to have interesting data in other contexts.

What did you learn about the data by using your visualizations?

- Variability in efficiency decreases as the pause time proportion increases.
- There are outliers for total time at both low pause time proportion and high pause time proportion.
- Total number of errors appears to be higher for students whose pause time proportion is less than 0.2.

How did you answer your questions?

- Filtering the values for pause time proportion allowed focus to be entirely on the values for total time, efficiency, and total number of errors opposed to looking for patterns across the entire data set.

How well does your visualization work?

- The visualizations functions as planned.

How could you further improve it?

- Adding additional small multiples to explore how pause time proportion interacts with other variables.
- Adding the ability to filter (or color code) the entire group of visualizations by either support level (honors, on-level, or support) or by cluster.
- Streamlining the design to address any concerns that come up from actual use.

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Summary

Overview and Motivation: Research suggests that increased pause time proportion is related to greater efficiency and fewer steps-to-solve. Our aim is to develop an interactive dashboard to allow further investigation of these relationships by filtering total time, efficiency, and number of errors by specific ranges of pause time proportion.

Related Work: The conceptual basis for the design of this dashboard integrated concepts from an article (currently in development which found evidence to suggest that increased pause time increases efficiency and decreases number of steps to solve) and coordinated views concepts discussed throughout the CS480x course.

Primary Question: How does filtering by pause time proportion impact the relationship between pause time and other variables (total time, efficiency, and total count of errors)?

Data: Log data was automatically collected as students played through From Here to There (FH2T; a discovery-based mathematics puzzle game).

Exploratory Data Analysis: Exploratory visualizations created in Google Sheets were used in order to understand the format of the data and inform variable choices to include in the dashboard prototyping.

Design Evolution: Five Design Sheet methodology (Roberts, Headleand, & Ritsos, 2016) was used to facilitate an iterative design process.

Implementation: Care was taken to try to make the UI as intuitive as possible.

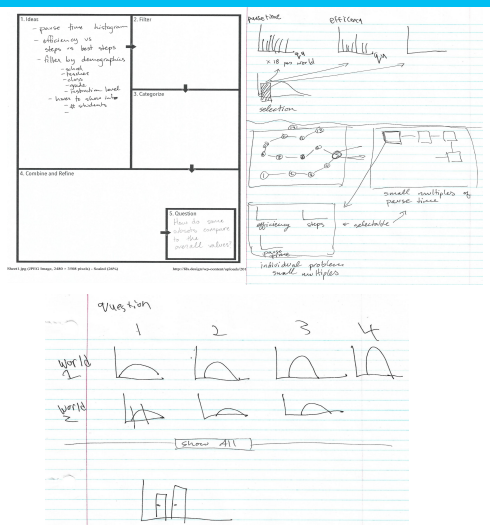
Evaluation: The dashboard functions as planned.

Future Steps: Due to the vast nature of the data there is plenty of opportunity for expansion of this dashboard to include more small multiples, other focus areas, or the ability to filter by demographics (support level, grade, etc) or clusters. Also, adding a tooltip on hover for the scatter plots to identify interesting points.

Appendix A

Full 5 Design Sheets

1



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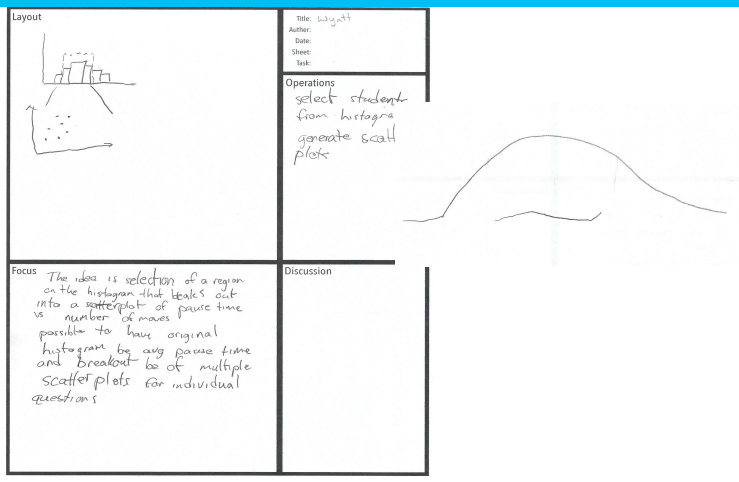

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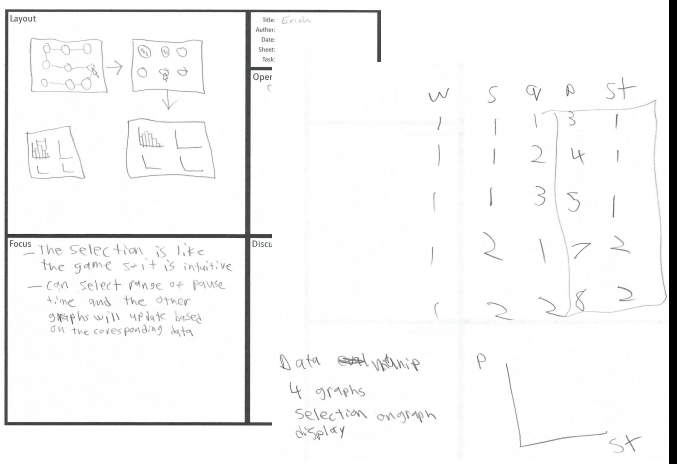

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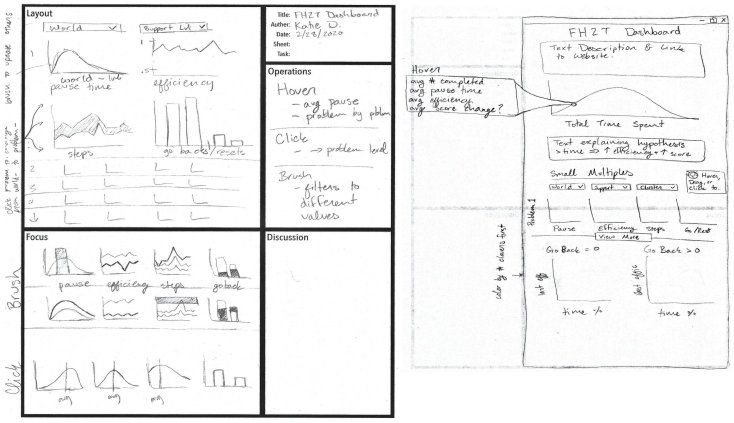

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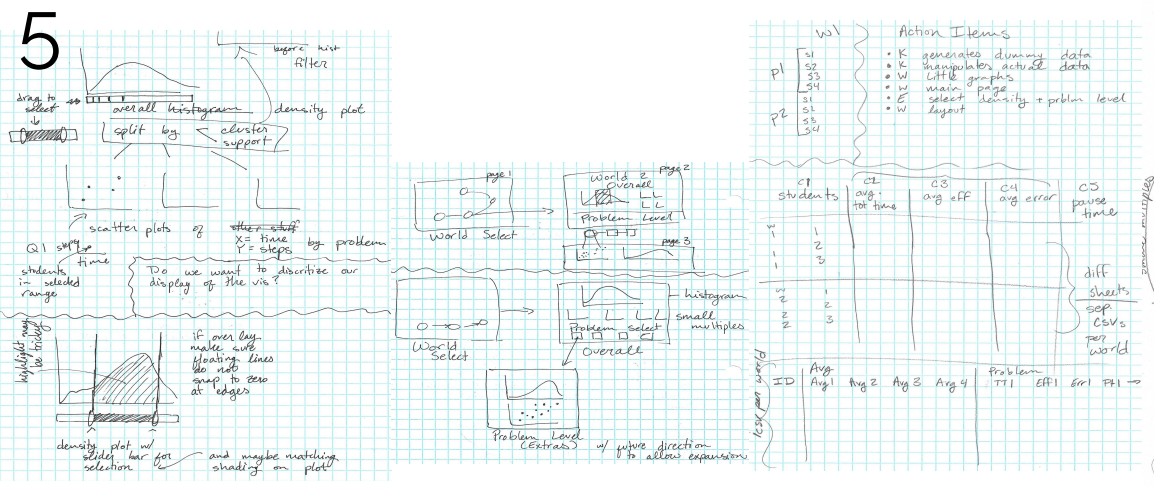
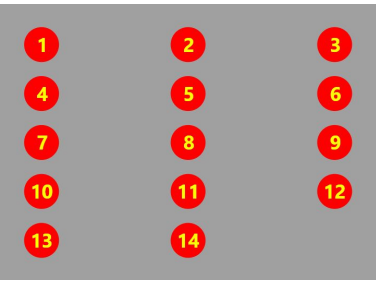
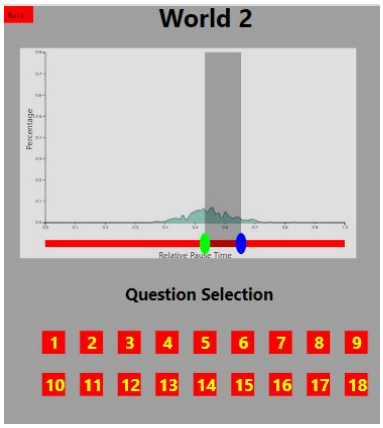
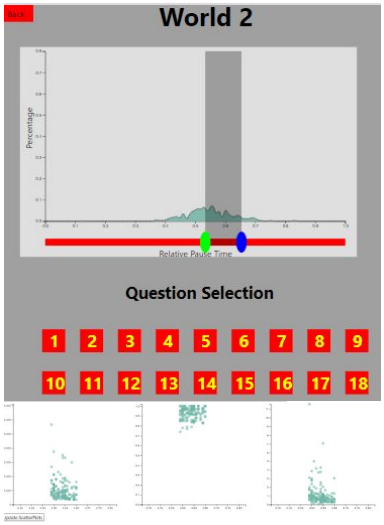


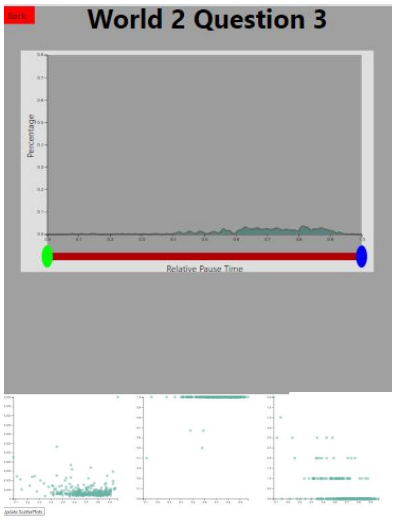
Appendix B

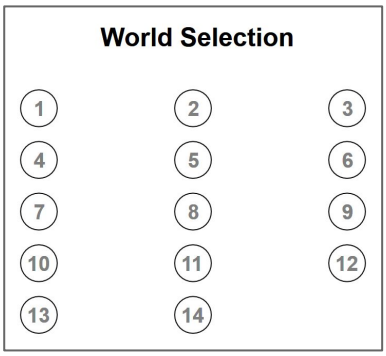
Transformation of Dashboard Design

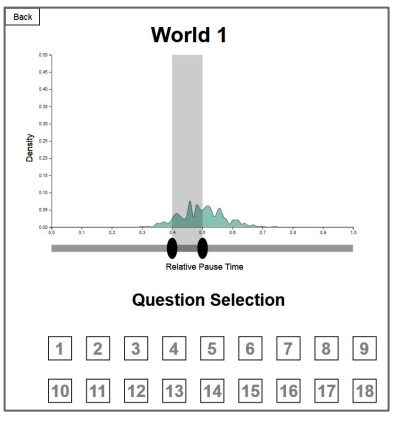


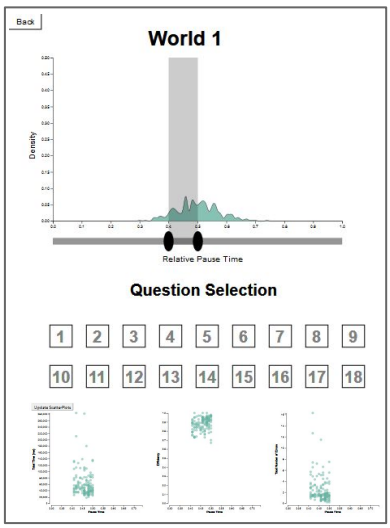


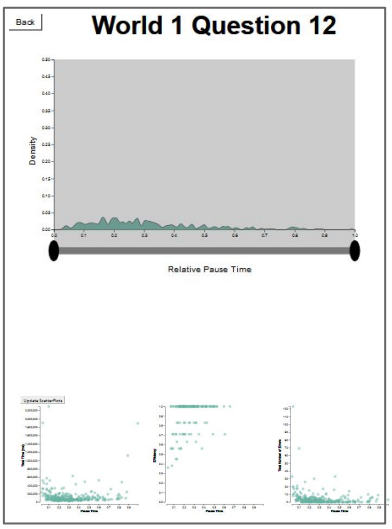












Appendix C

Non-Design Related Takeaways

- Log data is different beast than typical experiment data and understanding how everything goes together can be tricky.
- Collaboration and compromise go hand-in-hand.
- Fail early, fail often.
- Set concrete, actionable goals.
- Making progress means realizing things that you wish you would have known when you started the project.
- Communication, communication, communication!
- Having a good plan is one thing, having the plan be good is another.