# CREATING AN INTERACTIVE DASHBOARD TO SUPPORT MIDDLE SCHOOL TEACHER'S IMPLEMENTATION OF A TECHNOLOGY-SUPPORTED PROBLEM-BASED LEARNING PROGRAM

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In this design case, we describe our experience of designing and creating a teacher's dashboard as an accompanying tool to support sixth-grade teachers who implement a technology-supported problem-based learning program on sixth-grade space science in their classrooms. We describe in detail the background of this design case, our motivation to create this teacher's dashboard, and our iterative design process over a period of five years. Our design process consists of three phases from the idea generation phase to both low- and high- fidelity versions of the prototyping phase to three iterations of the implementation phase. We present our rationales for making various design decisions over the process and our reflections on this design experience including the challenges we have encountered.

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## INTRODUCTION

The purpose of this paper is to describe our experience of designing and creating a teacher's dashboard as an accompanying tool to support sixth-grade teachers who implement a technology-supported problem-based learning program on sixth-grade space science in their classrooms. A design case is "a description of a real artifact or experience that has been intentionally designed" (Boling, 2010, p. 2). The stakeholders of this design case are sixth-grade teachers for whom this dashboard is designed for, the designers and developers (a group of graduate students and the supervising faculty) who created this dashboard, and sixth graders who may benefit from their teachers' use of the dashboard in that the teachers can monitor students' learning progress more effectively using the dashboard.

In this design case (Boling, 2010; Howard et al., 2012), we document our iterative design efforts over five years. We describe in detail the background of this design case and our motivation to create this teacher's dashboard in the design context, three phases of design, and three iterations of implementation. We present our rationales for making various design decisions over the process, the issues we have encountered that added complexity to our designs, and finally our reflections on this design experience.

## THE DESIGN CONTEXT

### Background

The context of this design case is situated in a larger project called Alien Rescue (AR, https://alienrescue.education.utexas.edu). AR is an immersive multimedia enriched problem-based learning environment designed for sixth-grade space science. The goal of Alien Rescue is to engage sixth-grade students in solving a complex problem that requires them to use the tools, procedures and knowledge of space science and apply processes of scientific inquiry while learning about our solar system. Students, acting as young scientists are asked to participate in a rescue operation to find suitable relocation sites within our solar system for six different species of aliens who have been displaced from their home planets. To support students' inquiry process, a set of different features are built in the program. AR is designed as a curriculum unit on sixth-grade space science for about fifteen 45-minute class sessions and is delivered completely online. Up to this point, it has been used by thousands of middle school students and their teachers in 30 states.

The Alien Rescue design and development team consists of a group of graduate students (pursuing masters and doctoral degrees) in the Learning Technologies Program at the University of Texas at Austin. These students work collaboratively under the supervision and guidance of the faculty. Students' engagement in the project is largely driven by their interests in acquiring and applying instructional design and technical skills while creating a quality technology program. The design and development process of this larger project, Alien Rescue, is documented in the publication by Liu et al. (2014).

### Motivation

The underlining pedagogy for AR is problem-based learning (PBL). PBL is "an instructional (and curricular) learner-centered approach that empowers learners to conduct research, integrate theory and practice, and apply knowledge and skills to develop a viable solution to a defined problem" (Savery, 2006, p. 12). In PBL, the role of the teacher is that of a facilitator of instruction (Belland et al., 2008; Ge & Land, 2004). While sixth graders are interacting with AR as a self-contained curriculum unit to learn space science knowledge and practice problem-solving skills, teachers, as facilitators, are expected to monitor students' progress, provide feedback, and intervene as needed.

Our classroom observations revealed that teachers needed to know how their students used Alien Rescue so that they could apply appropriate facilitation strategies at appropriate times. We typically observed teachers in the local schools during their implementation of Alien Rescue project in the spring semester. Such observations were usually conducted once a year. Yet, before the implementation of this teacher's dashboard, the AR program lacked a way for teachers to know, just-in-time, what features their students were accessing and the information (e.g., notes) their students entered in the program. Without such information at their fingertips, it was difficult for teachers to know how their students' use of the program contributed to the overall problem-solving process. This challenge presented a new opportunity for the AR team. Therefore, we were motivated to create a dashboard as an accompanying tool for teachers within the larger context of Alien Rescue project. This dashboard served as a separate and yet connected tool allowing teachers to view, just-in-time, how their students were using the program.

A sub-team was formed to tackle this challenge, which consisted of five members of the AR team (four graduate students and the supervising faculty member). All these four graduate students had background in instructional design, one of them was a former middle school science teacher, and three had their research interests in learning analytics. The design of the teachers' dashboard took multiple years and comprised multiple phases from the inception of ideas to the implementation. In the following sections, we describe our design process.

## OUR DESIGN PROCESS

Our design consisted of three phases: Idea generation, prototyping (two static prototypes and three interactive prototypes), and implementation (three iterations).

### Phase 1: Idea Generation

The inspiration of how the dashboard should be designed came from two sources: What teachers (i.e. stakeholder) needed and what we (i.e. designer) wanted based on our experiences in working with teachers and our judgement on what Alien Rescue could be improved. We asked ourselves such questions: (1) what information from Alien Rescue program should be displayed? (2) how are dashboards designed in general? And (3) what information do teachers (a key stakeholder) want to have displayed?

Because this teacher's dashboard is designed to be a tool accompanying the larger Alien Rescue project, what is to be displayed will be related to the features built in AR program. A set of features are provided in AR to assist students' problem solving (Liu et al., 2013). Although each feature performs a specific function, three features are of most relevance to this design case as they are most interactive allowing students to enter information: Probe Design Center (a key feature to assist students' inquiry process), Notebook (for students to take notes while doing research), and Solution Form (for entering a solution to solve the problem as presented in AR) (see Figure 1 (a), (b), (c)). Notebook and Probe Design Center are interactive in that students not only enter information, but also depending on students' input,
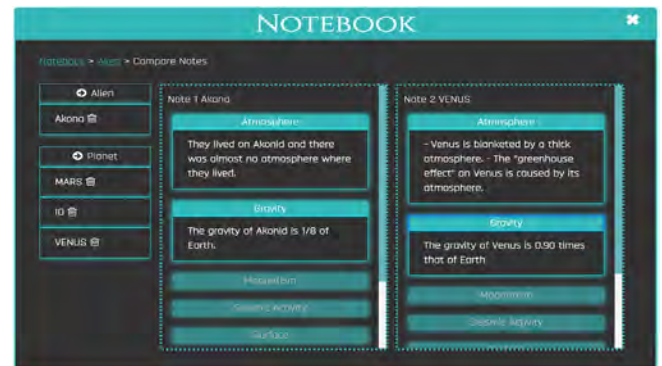
a. Probe Design Center


b. Notebook


c. Solution Form


d. Notebook Comparison Feature

**FIGURE 1.** Screenshot of three interactive features in Alien Rescue to support scientific inquiry.

the tools display different types of information. Notebook not only provides a notebook for students to type notes about their research findings, it also has a notes-comparison feature (see Figure 1 (d)) so students can drag their notes about an alien needs and a planet requirements side-by-side for comparison. Students can see the information they have already collected from using other features and figure out what is missing for further research. Once students have gathered sufficient information, they can design and launch probes in Probe Design Center where they research various scientific equipment instruments used in both past and present NASA probe missions, construct probes by selecting appropriate probe type, communication, power source, and instruments. Solution Form is a place for students to enter their final alien placement and rationale (i.e. which planet they choose as a new home for an alien species and why). These three features become a focus of our discussion on what information the dashboard should display. The description of these three features here will help connect to the design decisions and screenshots presented in Figure 1.

To get a sense of how dashboards were designed in general, we evaluated several websites that used dashboards (e.g., Khan Academy, Hapara, econsultancy). Two team members reviewed each and compiled notes for discussions among the team (see Appendix A for sample notes). At the same time, we sent out a survey, distributed online, to 12

sixth-grade teachers who used AR in the previous year and were using AR at the time when we sent the survey to get an idea about what information would be useful to them. We asked these 12 teachers their feedback because we believed their experience in using Alien Rescue would shed light on what worked well or not so well for them. Each teacher taught about 100 to 120 6th graders. The feedback from this purposeful sample of 12 teachers would reflect the use of Alien Rescue by over 1000 6th graders. We asked teachers such questions in both Likert scale and open-ended forms: (1) what kind of data/information from the AR program would you like to know in order to help you assess students' performance? (2) what data would you be interested in viewing on students' probe design? (3) what data would you be interested in viewing on students' alien placements? (4) what data would you be interested in viewing on students' notebooks? The survey data were analyzed descriptively. Figure 2 shows teachers' desire of displaying the three features.

Teachers' feedback from the survey helped us decide what we wanted to prioritize and include in the dashboard. We, the design team, had many rounds of weekly discussions over an extended period of time. Given the evaluation of other dashboards and teachers' feedback, we brainstormed and came up with an outline of all possible and desired features to consider in the dashboard while paying close
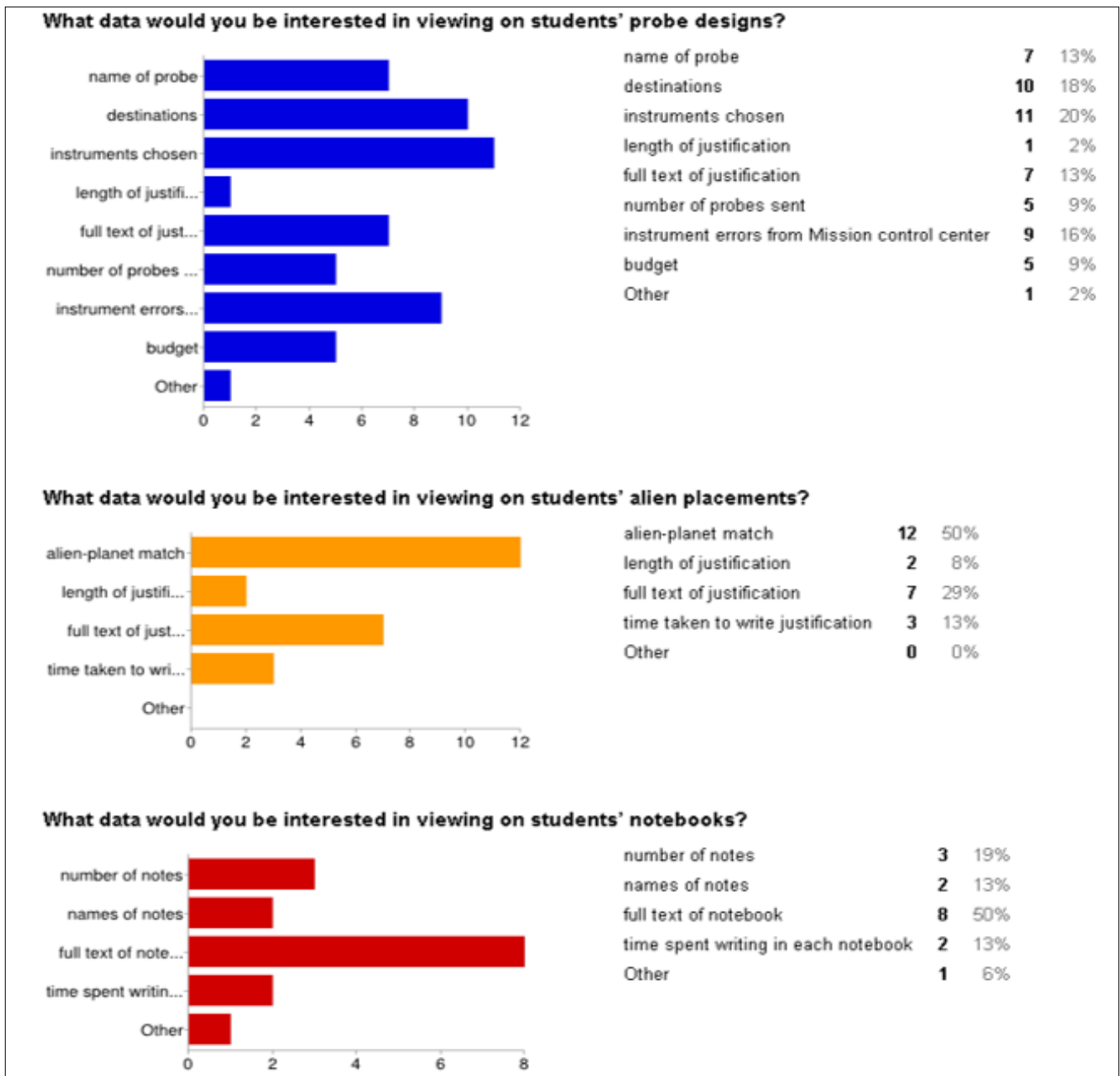
**What data would you be interested in viewing on students' probe designs?**

| | | |
|---|---|---|
| name of probe | 7 | 13% |
| destinations | 10 | 18% |
| instruments chosen | 11 | 20% |
| length of justification | 1 | 2% |
| full text of justification | 7 | 13% |
| number of probes sent | 5 | 9% |
| instrument errors from Mission control center | 9 | 16% |
| budget | 5 | 9% |
| Other | 1 | 2% |

**What data would you be interested in viewing on students' alien placements?**

| | | |
|---|---|---|
| alien-planet match | 12 | 50% |
| length of justification | 2 | 8% |
| full text of justification | 7 | 29% |
| time taken to write justification | 3 | 13% |
| Other | 0 | 0% |

**What data would you be interested in viewing on students' notebooks?**

| | | |
|---|---|---|
| number of notes | 3 | 19% |
| names of notes | 2 | 13% |
| full text of notebook | 8 | 50% |
| time spent writing in each notebook | 2 | 13% |
| Other | 1 | 6% |

**FIGURE 2.** Screenshot of teachers' desire of displaying Probe Design Center, Alien Placements, and Notebook which are the focus of this design case.

attention to the three features: probe design, alien placement, and notebook. A typical meeting went like this: Team members gave updates on what they were working on. The whole team provided feedback/suggestions and asked questions. Discussing the design of dashboard was one of many discussion topics at the weekly meetings in addition to discussions on other topics relating to the larger Alien Rescue project. We discussed teachers' feedback in detail and what solution we could provide. Sample features included displaying information through tabs, management capabilities (e.g., add/delete a student), displaying an overall snapshot of the whole class activities in terms of tool use,

and displaying an overall snapshot of an individual student's activities in terms of tool use, notes created, probes created, and alien placed. The following shows an example of the list of features we came up through our brainstorming. Appendix B provides the full outline.

- Tabs
  - My Classes (multiple classes as a teacher typically teaches 5-6 classes)
  - My Class (one single class)
  - Manage Students–add/delete students, place into groups, send a message, take screenshot, adjust

budget (a budget is provided in designing probes), sort to find a student
- Student Name
- Can have multiple classes open at a time

• Overall snapshot of class activity
- Map of space station that shows where students are
- Aggregate Action Shape, plus capability to separate into groups
- Topics most visited in Databases
  › Alien
  › Solar System
  › Concepts
  › Missions
- Total notes created
  › Leaderboard with top 10 (based on character/word count?)
  › Word cloud for notes–general one automatically generated on homepage, but teachers can create new ones for specific note titles
- Total probes created
  › Leaderboard with top 10 (based on % new information)
  › Word cloud for probe justifications
  › Breakdown of probe destinations by associated alien (or none)
  › Probe errors
    » % of instruments
    » Broken down by cause
- Total aliens placed
  › Leaderboard with top 10 (taking accuracy into account)
  › Word cloud for justifications
- Activity feed that shows notes created, probes designed, and recommendations submitted in real time (with timestamp)

**Phase 2: Prototyping**

In Phase 1, we addressed the question "What information needs to be displayed on this dashboard?" Here in Phase 2, we aimed to address "How should such information be displayed on this dashboard (i.e. structure, aesthetics, and usability)?" We made multiple prototypes from static to interactive ones. First, we made a paper sketch and another one using Google Slides (see Figures 3 and 4).

These static versions were limited in terms of playing around our design ideas visually, especially in showing how each section related to another. We decided to move from low fidelity prototypes to higher fidelity ones. We chose Axure RP (https://www.axure.com), a wireframing and rapid prototyping tool. It allowed planning and prototyping with interactive features without writing codes. Using Axure RP, we created three interactive prototype versions, each built upon the previous one, to further refine our ideas. Prototype
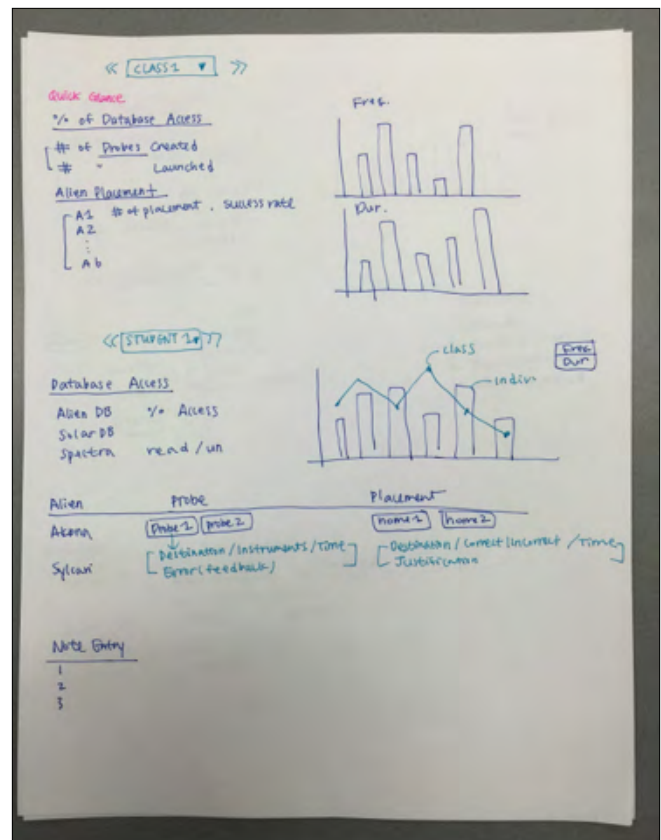


**FIGURE 3.** Paper sketch prototype illustrating the ideas discussed in Phase 1 to be displayed in the dashboard.

1 created a structure of the dashboard as shown in Table 1 and visual representations of the ideas (Figures 5 and 6).

Figure 5 shows various features in these sections. For example, under Class Activity, it first shows an overview of the class including students' username when they register for the program, ID, their first and last name (Figure 5 (a)). Figure 5 (b) shows overall class activity in using the various features built in AR such as frequency of tool usage along with the class average, topics students visited, number of notes taken, number of probes designed, alien placements, and class activity feed. An interest for the team was to visualize the data so teachers could quickly get an idea of how her students were doing. We also thought having a leaderboard would be interesting and gamifying. The possible leaderboard ideas were also illustrated (e.g., who created the most notes, launched most probes in Figure 5 (b)).

Figure 6 shows individual student activity–frequency of each feature as well as how much time a student uses a feature, the notes a student has taken and word count for each note. This information tells a teacher how a student uses the features provided in AR so the teacher can monitor the student's progress. It shows the destination of each probe this student sent and which planet for which alien species the student has chosen as a solution (the final step in using the
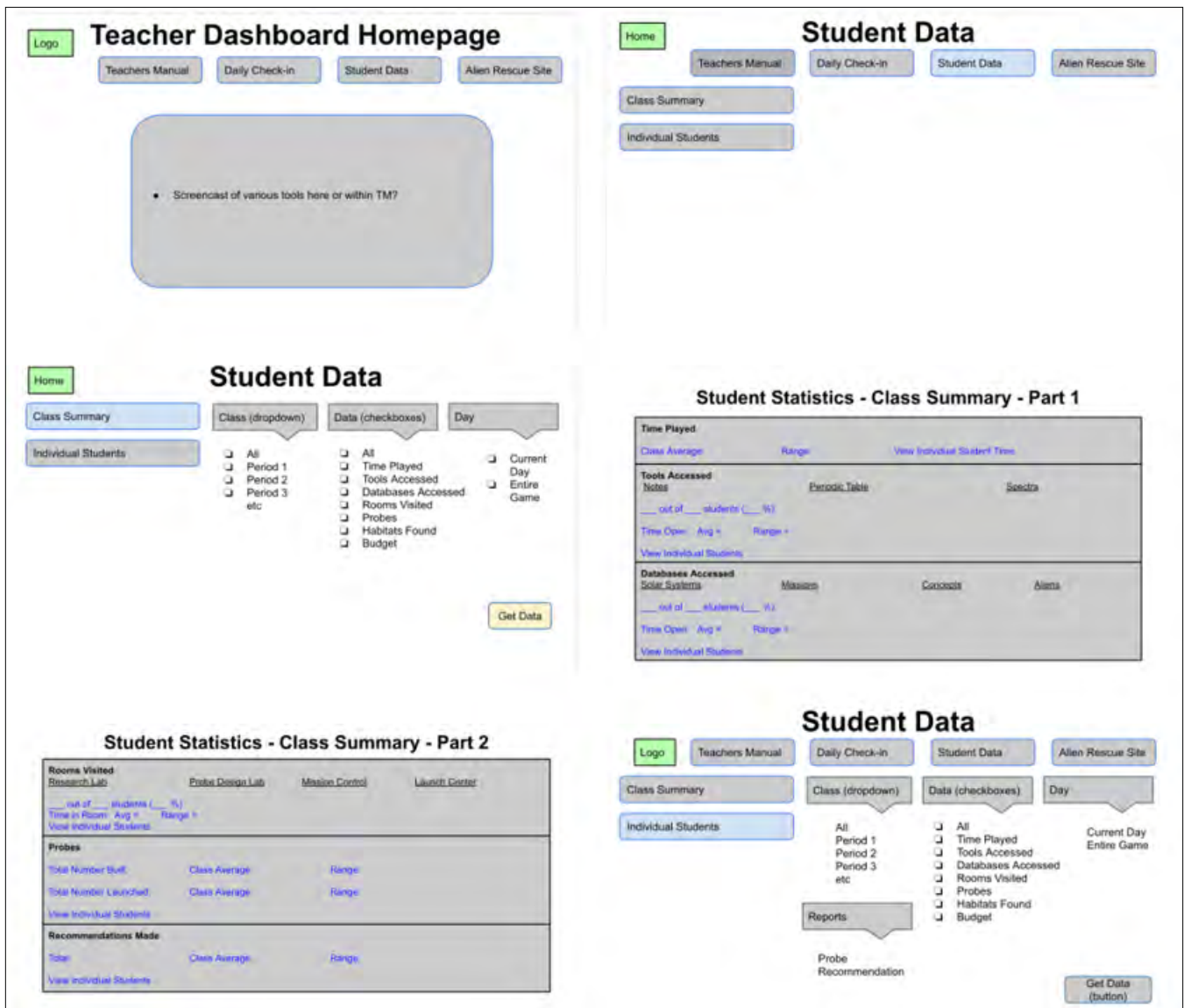
**FIGURE 4.** Prototype using Google Slides providing more detailed illustrations of the ideas discussed in Phase 1 to be displayed in the dashboard.

| NAME OF PAGE | PURPOSE OF PAGE |
|---|---|
| Class Activity | Displays aggregate data on a class that teachers can use to monitor activity |
| Individual Report | Displays data on individual students that teachers can use to monitor activity |
| Grading Tools | Displays data on individual students that teachers can use to grade. Expanded and Compacted are re-formatted so that all tools function the same way |
| Print Report | Interface for teachers to select and create their own reports for printing, incorporating teacher's feedback |

**TABLE 1.** Ideas of overall structure of the dashboard representing what a main menu may look like.

program). Such information is important to assist grading so the teacher can know if the student has solved the problem correctly.

This prototype allowed the team to see how various ideas we came up during many brainstorming sessions in Phase 1 could be possibly realized. It was also a concrete way to think about the usability which prompted new questions for further discussions (see Appendix C for more information).
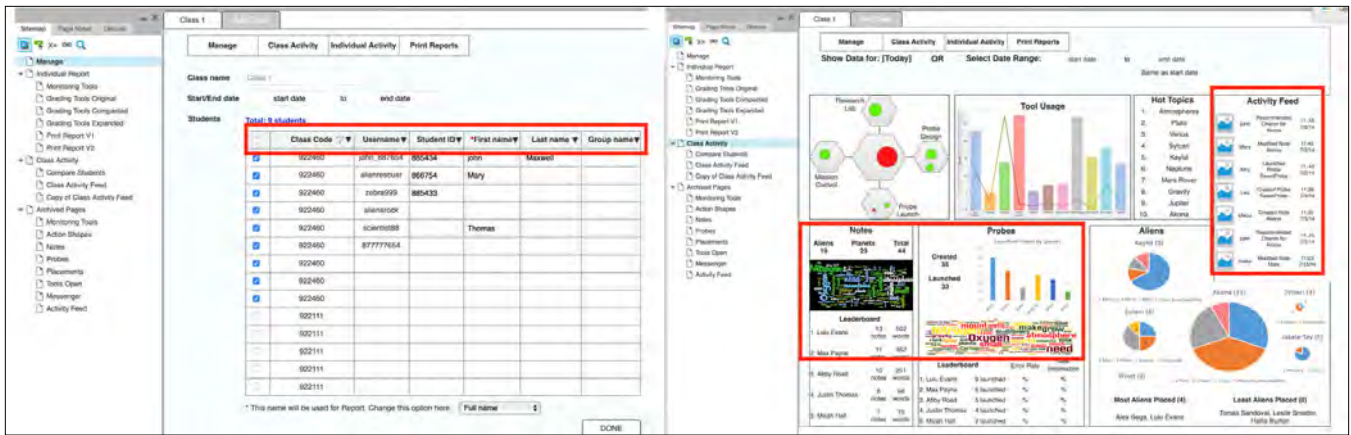
**FIGURE 5.** Prototype showing class activities (i.e. how students use various features in AR as a class) in tabular and graphic forms.
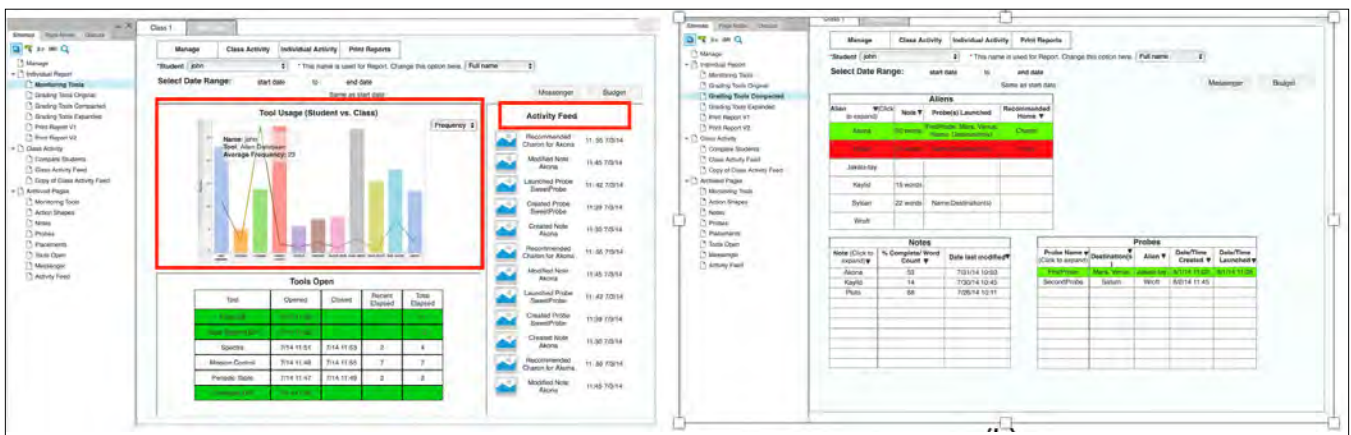


**FIGURE 6.** Prototype showing individual student activities (i.e. how each student is using various features in AR) in tabular and graphic forms such as tool usage and activity feed and choices a student selected.

Seeking teachers' feedback was a critical step in our design process. We sought feedback from the teachers through classroom observations and informal interviews each year as they implemented Alien Rescue in their classrooms. In this design case, once we had a prototype in Phase 1, we showed this interactive prototype to the sixth-grade teachers in the classrooms who used AR previously and were using AR at the time. The teachers really liked the idea of having a dashboard as an accompanying tool, so they were able to see the notes their students created and especially the probes their students sent. For example, one teacher said, "Some of the kids are struggling with probes. We don't like that as we cannot see how the kids designed the probe after a failure of data returned. It would be easier to teach if we had evidence." Another teacher commented: "That all sounds great. I would love to have the students submit in the program, but as a project grade I need to see their results. In the future a way to get things to us that they submit in the program would definitely help." Up to this point, teachers could not view such information their students entered in the program. Some teachers started to use

Google Docs for students to enter notes and their solutions or asked students to write down the information on paper in addition to entering in AR. This added additional work for the students as they had to enter information twice (once in the program and then on paper or via Google Docs). Although the ideas of various visuals we proposed (e.g., leaderboard, class feed, word cloud, bar graphs and pie charts, see Figures 5 and 6) were interesting to teachers, it was apparent that the information from this prototype was overwhelming, and the design was hard for teachers to figure out what each piece of information meant and how to make sense of the information.

Building upon Prototype 1 and given teachers' feedback, we made several major changes in Prototype 2: (1) Eliminated class feed, word cloud, leaderboard ideas; (2) kept four sections on Class Activity: Tool Usage, Alien Placement, Probes, Notebook Access to make the screen less cluttered (see Figure 7).

In addition, Notebook displayed the actual notes a student created. Solution form (alien placement) not only showed
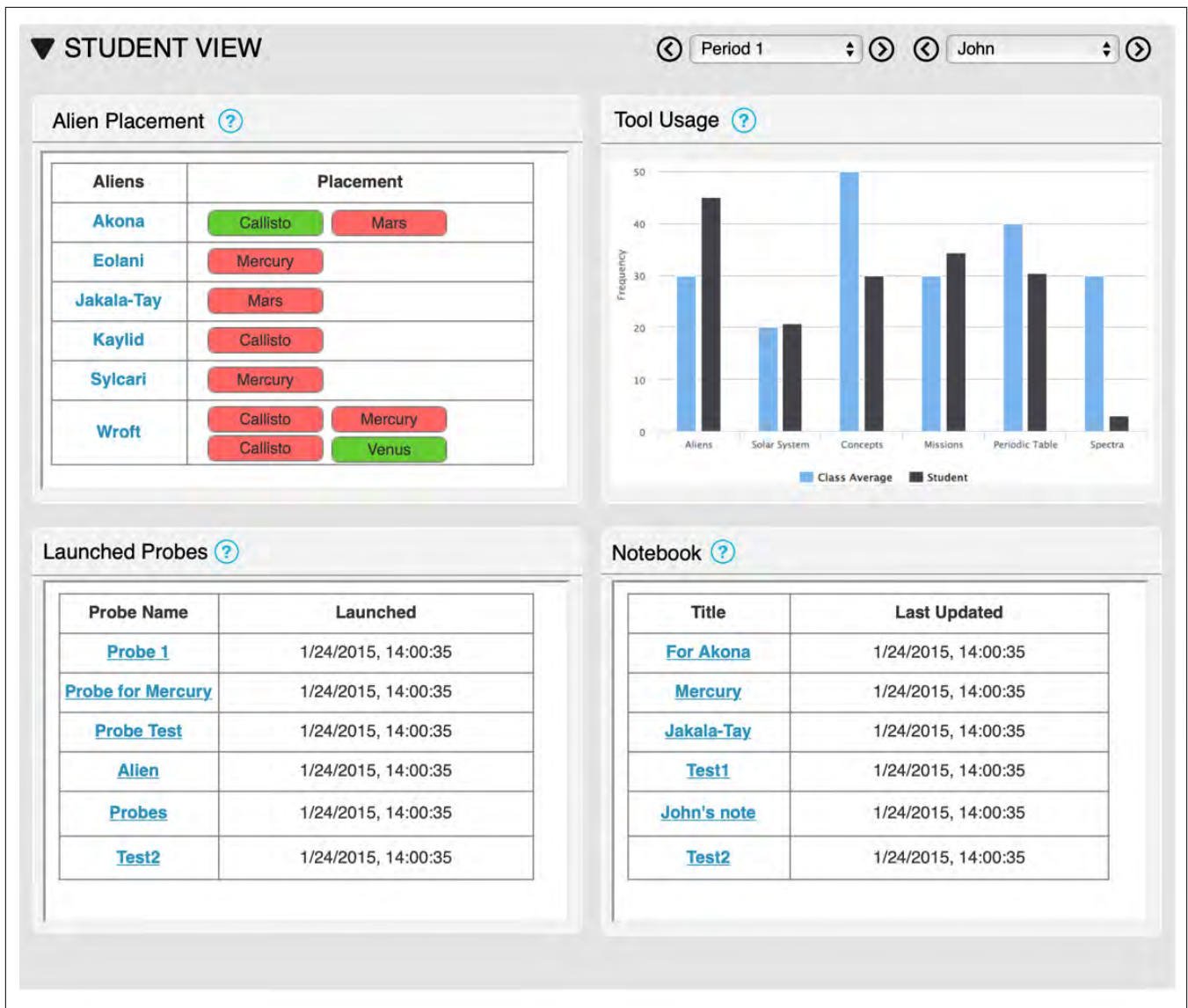
**FIGURE 7.** Revised prototype showing a simplified version of displaying student activities.

each recommendation for each alien species a student made, but also the justification by the student. Knowing justification could help a teacher understand a student's rationale behind the solution. For probe design, in addition to the destination a probe was sent, it showed the power source, communication, and instruments selected. Using a button format, red color indicated an incorrect placement and green color indicated a correct placement. These features were important to assist teachers' grading in a more efficient way (see Figure 8).

Prototype 2 was better received by the teachers. Teachers liked the idea of having an overview for the class (i.e. Class Activity) and then individual student activity view. It was also clear that the teachers were most interested in viewing the information students entered in the three features: probes, notebook, and alien placement. This reinforced our design

focus to create a useful dashboard for teachers who were interested in using AR in their curriculum. In Prototype 3, we made additional minor adjustments, including adjustments in navigation and layout of information on each page.

**Phase 3: Implementation**

Three interactive prototype versions as discussed in Phase 2 moved our goal of designing a dashboard for teachers closer to implementation. The next step was to consider what technologies to use to bring our ideas to realization. Because our team consisted of graduate students in the Learning Technologies Program, we needed to consider what technical skills the team members had and could learn to be able to create the dashboard. We identified the requirements into "must," "can do," and "desired" features and focused on those "must" and "can do" features. We further separated into "high priority" which included "must have" features and the
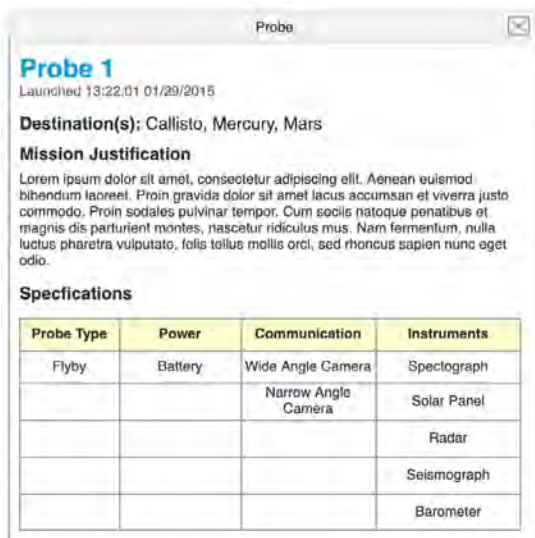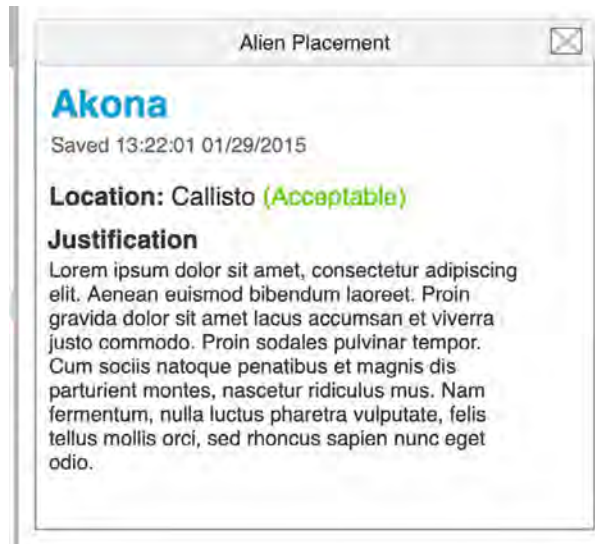
A.                                                                    B.

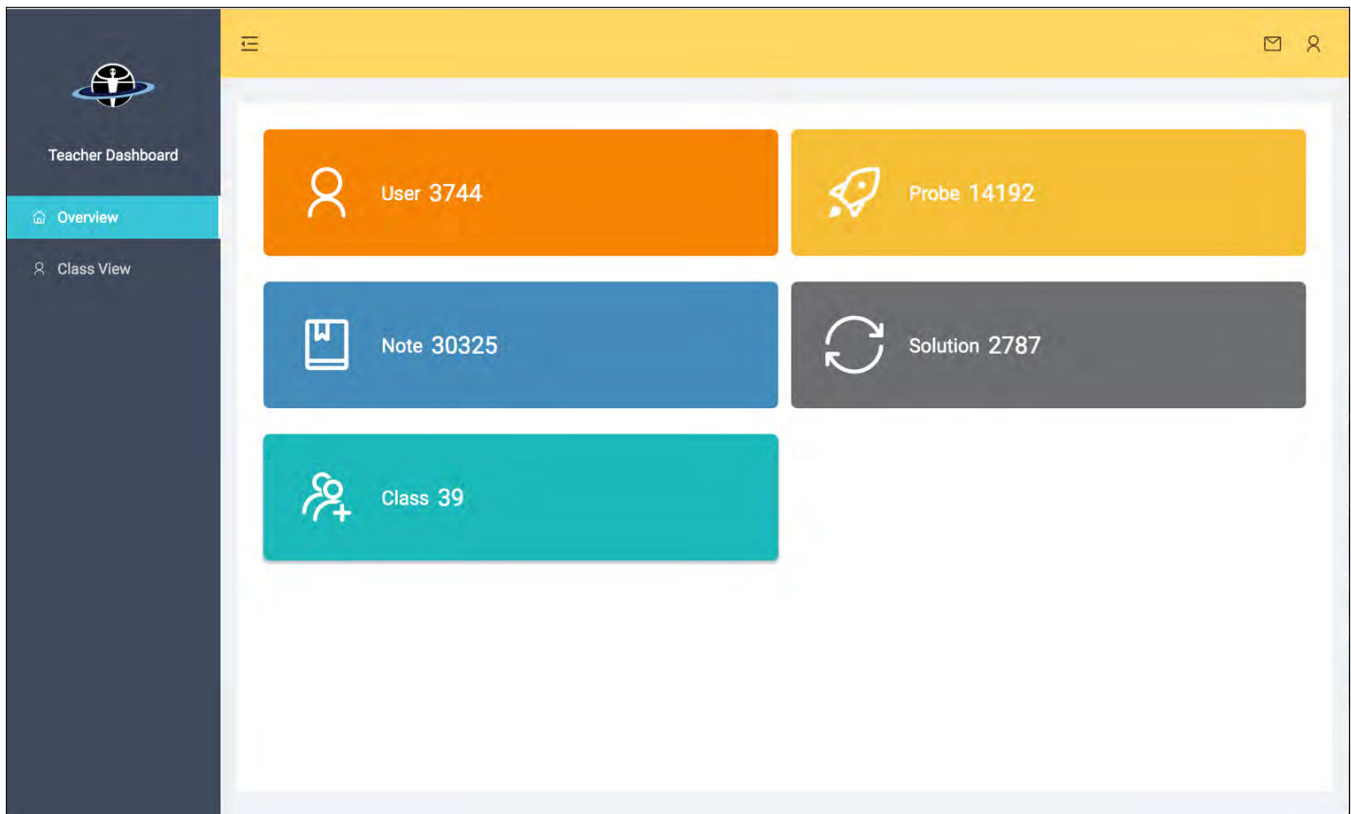**FIGURE 8.** Revised prototype allowing teachers to view the details of a probe designed by a student (a) and an alien placement (b).



**FIGURE 9.** Implementation–Overview page with a tiled structure.

skills we had to implement vs "low priority" features which included desired features and/or we currently did not have the skills to implement. As team members continued to learn technical skills, more features were added, and existing features were improved.

We decided to use open-source platforms to develop the teachers' dashboard so that our development would not be constrained by potential and inevitable changes in proprietary software. React.JS (https://reactjs.org/) was selected as the core infrastructure for user interface (UI). React.JS is one of the most popular UI frameworks in the web development field due to its readable syntax as well as ease

of reusing existing codes. Alien Rescue program itself also used React.JS for UI development, and using React.JS for the dashboard allowed us to easily recycle the data structure and UI components used in AR. Given the choice of React.JS, we then chose a React-based UI library Ant Design (https://ant.design/) which is natively written with React.JS and offers various ready-to-use UI widgets that we can customize. Since the main goal of the dashboard was to serve as the reporting platform of students' activities within AR, instead of having a separate server we decided to extend the existing AR server built with Express.JS (https://expressjs.com/) and MySQL (https://www.mysql.com/) by implementing new application programming interfaces for the dashboard. Express.JS is a popular framework to build a serving application to communicate between web apps and remote servers. MySQL dominates the market of relational database that offers fast and scalable data storage and retrieval. An important component of the extensions of the AR server is the use of the websocket technology. The web-socket technology allows users to sustain a connection with a remote server and thus conduct a two-way communication (users->server and server->users), which lays the foundation for real-time communication. Once we decided on the technical tools, we began to learn the tools to develop the dashboard. While the design prototypes provided a basic blueprint for implementation, we made adjustment along the way (e.g., labels, layouts of screens, structure) as we got familiar with the technical tools and what the selected technologies allowed us to do. As we improved our technical skills, we also improved the functionalities of the dashboard.



**FIGURE 10.** Implementation—Class View page giving a teacher an overall picture of her class activities.



**FIGURE 11.** Implementation–Probe View page.

*First Iteration of Implementation*

The first iteration of the dashboard implementation focused providing a "Class Overview" feature as it was determined a "must have" feature from our team discussion. Because one teacher could have multiple classes, showing all classes available before a class was selected in the landing page would cause crowded or empty screen. We decided to use a tiled screen that showed descriptive statistics on a teacher' classes as the landing page (see Figure 9). This landing page was named as "Overview." There were five tiles in this "Overview"
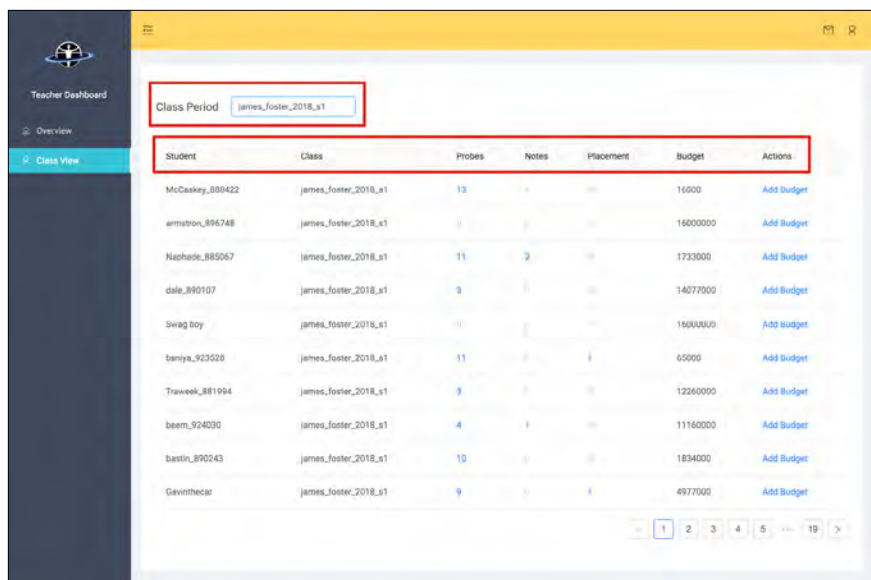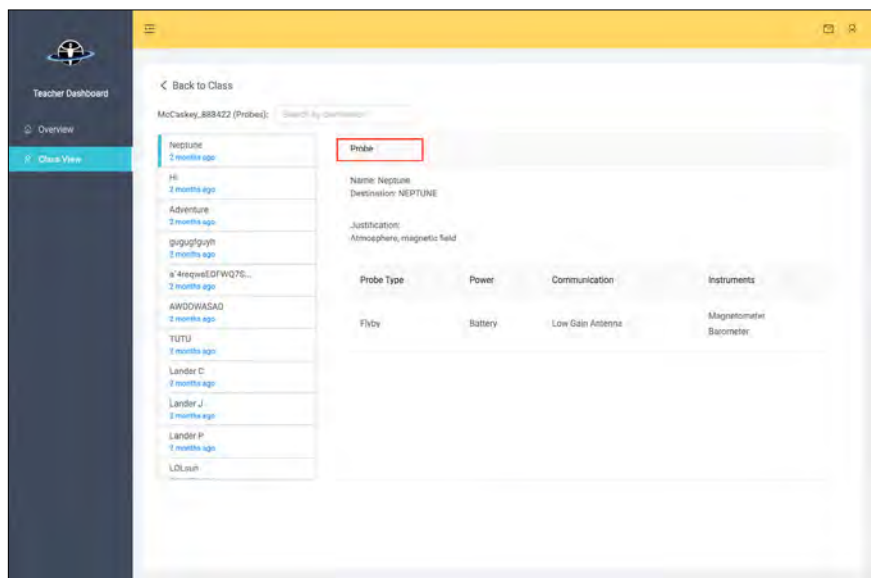
page: "User," "Probe," "Note," "Solution," and "Class." Each tile had a name and number presented. The number in each tile showed the total number of a certain attribute a teacher had in her class(es). For example, the "User" tile in Figure 9 had a number of 3744 meaning there were 3744 students that had used the group code(s) of the teacher to register in AR. Similarly, the "Probe" tile's 14192 meant there were 14192 probes submitted in the teacher's classes.

"Class View" page at the same navigation level of "Overview" showed the overview of activities by a class. A search bar in the "Class View" allowed a teacher to search a specific class. Similar to the Google search bar, the search bar in "Class View" provided auto-complete suggestions based on the

search terms, while search suggestions were limited only to the classes that teacher taught. Once a class was selected, descriptive statistics on students' overall activities would be displayed, showing in a paginated tabular format of seven sections: "Student," "Class," "Probes," "Notes," "Placement," "Budget," and "Actions" (see Figure 10).

 "Student" section displayed students' usernames in AR. "Class" section denoted which group code (each class was identified by a group code) the student belonged to. "Probes," "Notes," and "Placement" sections showed the number of probes, notes, and solutions a student created respectively. The numbers in the blue color suggested these numbers were clickable and numbers in grey indicated they were not. The "Budget" section presented the remaining budget of a student had (creating probes costs money). The "Actions" section allowed teachers additional functionalities such as increasing the budget for a student.

Clicking on blue numbers under the "Probes" section allowed a teacher to see detailed information on probes submitted by a specific student (see Figure 11). The "Probe View" showed the student's name on the top left. Next to the student's name, there was a search bar that allowed teachers to filter probes by destination (planets). Below the student's name and search bar, on the left side, there was a list of probes sent by the current student. Once a destination was searched, only probes sent to the destination showed up. The probe list was scrollable in case a student sent a large number of probes. The probe list was sorted in a date-time descending order, so the latest sent probes would be shown on the top. Each item in the probe list showed the name of a probe and time when the probe was created. Each item in the probe list was clickable to show detailed information of a probe such as a probe's name, destination, justification, and probe configurations (probe type, power source, communication tools, and data collection instruments).

The interface and functions of the "Notes" and "Placement" sections were similar to the "Probes" section. A teacher could view the notes a student took and solutions a student submitted (see Figure 12 (a) and (b)). Such consistency in design and user experience would ensure consistent navigation for a user, and also allowed the developers to reuse codes.

We emailed the teachers who planned to use AR to provide a summary of our rationale of designing this teacher's dashboard and explained the progress we made. We then took this first iteration of the dashboard to teachers as they were using AR in their classrooms for feedback. We demonstrated the dashboard features and how to use it. One teacher said, "Teachers' dashboard was so helpful to see probes sent and teach students how to learn from mistakes," and another commented, "I think this was the best year so far for Alien Rescue. I enjoyed the dashboard and those new features. I appreciate you working with us to optimize the program." Being able to see the notes students took, the detailed information of probes they sent (e.g., probe types, instruments), and solutions students entered were the features teachers really liked. They indicated these features helped them understand their students' problem-solving process and allowed them to provide additional support to students who needed it. One teacher stated she could now "go back and look at individual probes students sent and help them understand why errors happened and what to do next time to get the data they want." In AR, if a probe is properly designed, it will return useful data to further students' problem-solving process. Yet, a poorly designed probe will return errors. This first iteration of the implementation realized the three most important features the teachers wanted to have as they expressed in Phase 2. Based on teachers' feedback as well as our classroom observations of teachers' use of this first iteration of implementation, we decided to make several improvements during the second iteration as discussed in the next section.
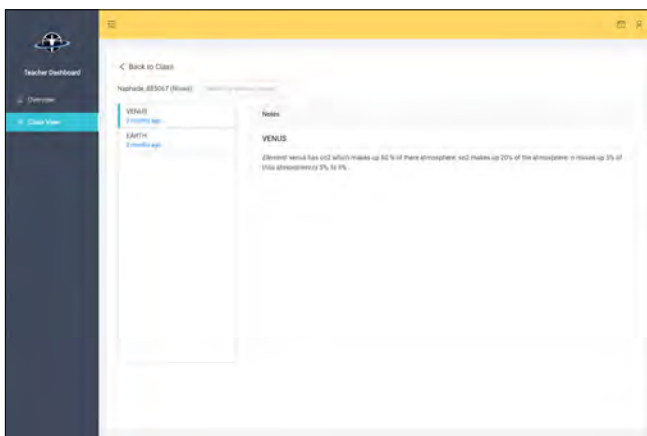


a. A student's notes
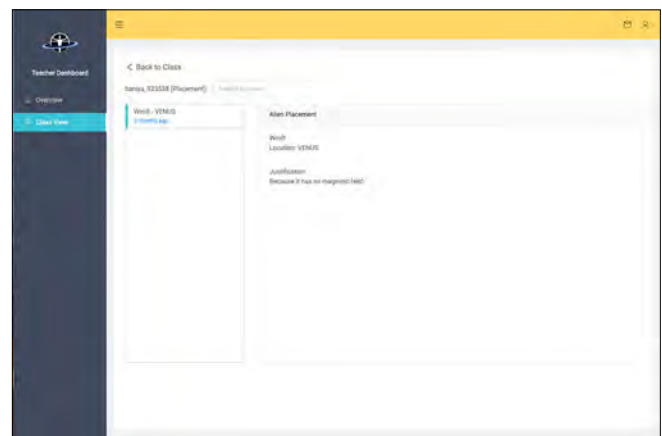


b. A student's placement

**FIGURE 12.** Implementation–Notes View and Placement View pages.

*Second Iteration of Implementation*

While keeping the features shown in the first iteration, several new additions were made in this second iteration. First, several new features were added in management functions for the "Class View" page. We learned from teachers' feedback that it would be useful if teachers could search by students' names. Since a class as identified by a group code could have more than 40 students, it was hard for teachers to find a specific student quickly in "Class View" page. Moreover, at the time of the first iteration, students were not required to input their first and last names during the registration. It was often difficult for teachers to associate students' usernames with their real names, as students often made-up names for their usernames. We addressed this challenge by adding another search bar right next to the class search bar that allowed a teacher to associate students by names (username, first name, and last name). Meanwhile, we also made a change for the registration process asking students to enter their real names as well as usernames. Students' real names were displayed under the "Student" section. Another new feature we added was to allow teachers to reset students' passwords. Teachers reported that some students forgot their passwords in the middle of using AR and asking students to re-register would lose all the saved information. They requested a feature to reset students' passwords. A new action "Reset Password" was added under the "Actions" section to allow teachers to change students' passwords if needed (see Figure 13). Lastly, we added a feature to allow teachers to download all the data displayed in "Class View" as a comma separated value (CSV) file if teachers hoped to analyze the data in external tools.

The second major change was to add a feature showing how students' use of each feature in a visual way both as a class and individually. Teachers mentioned they would like to see the number of minutes their students spent in Alien Rescue so as to determine which students were rushing through and which were spending enough time on the problem. This new feature ("Report - Class" and "Report - Student" pages) showed how students as a class and individually used the tools in detail. These two pages displayed the information visually in the same way.
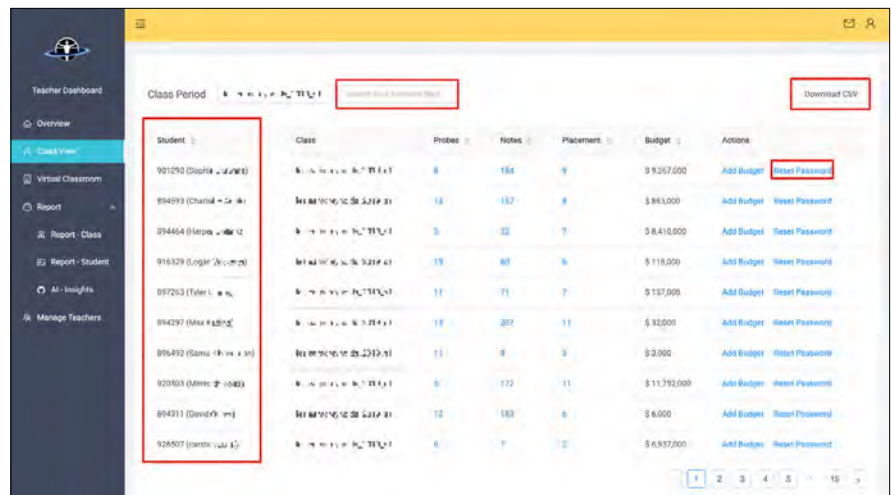


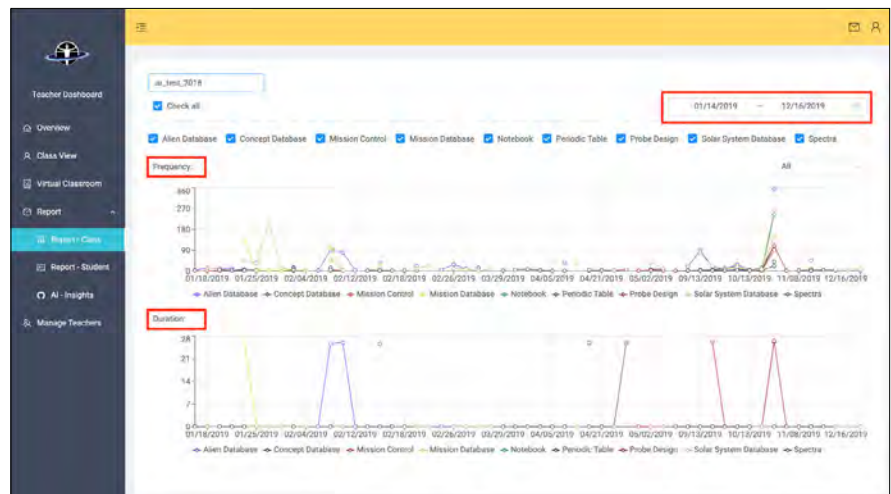**FIGURE 13.** Second iteration of implementation showing improved display of information.



**FIGURE 14.** Second iteration of implementation showing two new features: Report–Class and Report–Student pages.

While "Report - Class" page showed visualization in the unit of class, information on "Report - Student" page was in the unit of an individual student. For both pages, a search bar allowed teachers to search by class or student. Teachers could also use the calendar widget on the top right corner to filter activities by dates. By default, the calendar widget spanned from the date when the first activity was taken to the date when the last activity was taken. Two line-graphs were displayed to show students' tool use in frequency and duration, respectively. Teachers could use the checkboxes on the top to toggle the visualization of different features. The frequency graph (see Figure 14) had a Y-axis of counts and X-axis of dates, and the duration graph had a Y-axis of minutes, and X-axis of dates. By using the report pages, teachers could easily understand the general patterns of students' feature use from day to day. A teacher could intervene and help students if she saw a student used one feature too many times but did not use other features; or

spent too much time in some features but not enough time in other features.

*Third Iteration of Implementation*

In this third iteration, our focus was to utilize artificial intelligence (AI) techniques to enhance teachers' facilitation. A key problem-solving activity in using AR is after students have gathered data through their research, they will design probes to test their hypothesis. When sending a probe, a student is asked to construct a probe, select a destination, and also provide a justification why sending a probe to a specific planet is needed. The justification is written in text and it is not easy for teachers to read many justifications quickly during the limited class time to intervene if the student is on the wrong track (i.e. students do not have a reason to send a probe). In our other research exploring various artificial intelligence techniques (Pan et al., 2021), we tested various models to automatically process a large amount of textual data from the analytics in the previous AR use to understand students' scientific argumentation as shown in probe justifications. Specifically, two researchers coded 4,500 text-based probe justifications with scientific argumentations to construct a training dataset for the AI model. During the coding, the researchers reached high inter-rater reliability of 0.84 measured by Cohen's Kappa on 500 samples. 70% ($n = 3,150$) and 30% ($n = 1,350$) of the dataset were used

as training and testing sets, respectively. We then trained a deep neural network model called Bidirectional Encoder Representations from Transformers (BERT by Devlin et al., 2018). BERT was benchmarked against several machine learning models commonly used in learning analytics, such as Random Forest and Recurrent Neural Network (RNN). The results showed that BERT greatly outperformed the benchmarks by approximately 6% on accuracy and 10% on F-measure. The superior performance of BERT (accuracy of 90% and F-measure of 85%) allowed us to auto-classify text justifications into several theory-driven categories from poorly justified arguments to well-justified arguments. Given this result, we incorporated this auto-classification feature into the design of the teacher's dashboard to enable teachers to see students' justifications in a quick way to assist their facilitation. Figure 15 shows an example of what teachers see on the dashboard. Different colors represent different types of scientific argumentation students have composed. There are five types of scientific argumentations ranging from random (poorly-justified arguments) to reasoning (well-justified arguments) based on a scientific argumentation framework (Bogard et al., 2013; Liu et al., 2015, 2016). For example, Figure 15 shows students sent a relatively larger portion of random justifications on Oct. 22 as shown in red color. Using this information, a teacher can quickly see whether her students' justifications are on the right track and what additional support she needs to provide. At the point of this writing,
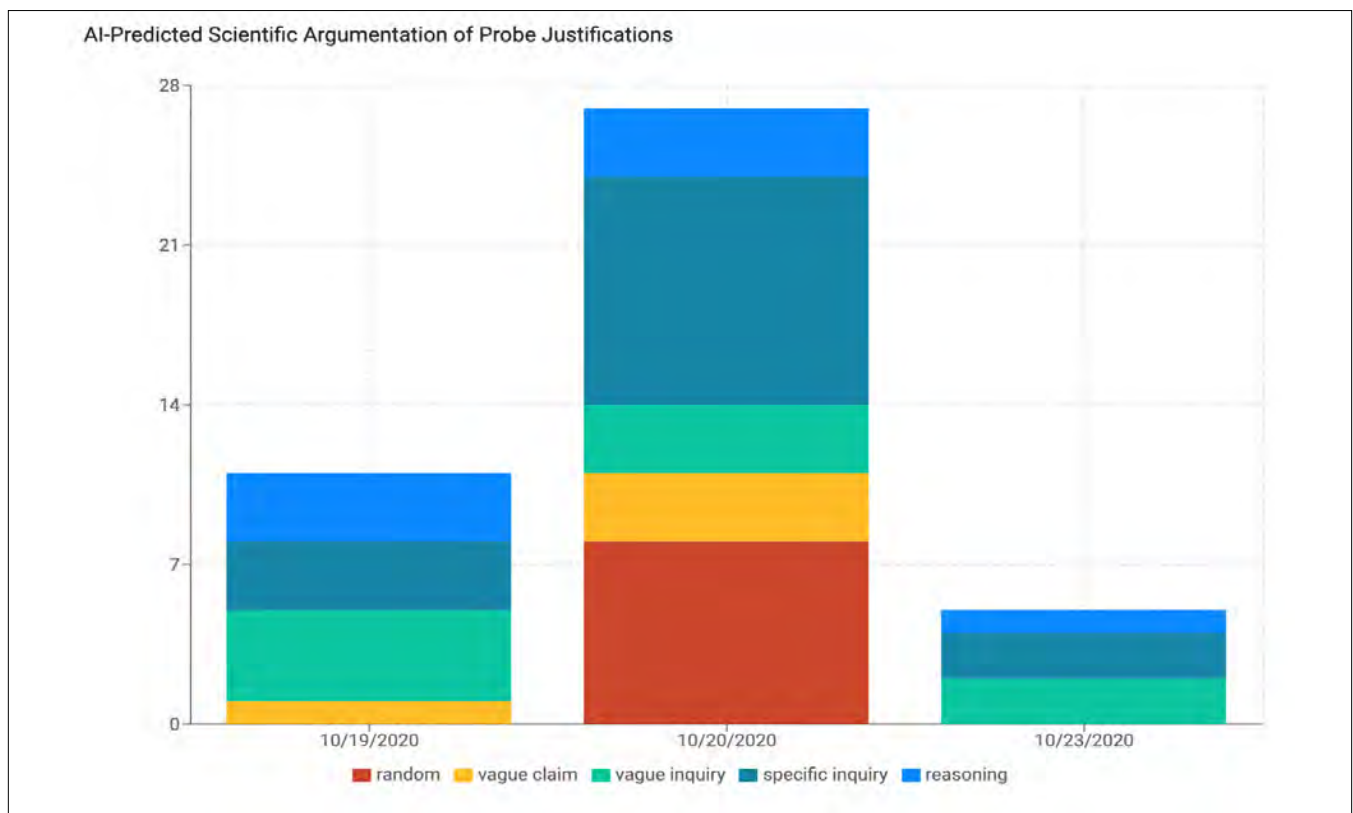


**FIGURE 15.** Third iteration of implementation showing an example of a visual representation of classified students' probe justifications using artificial intelligence techniques (Y-axis indicating number of justifications).

we have implemented this feature in the dashboard and have made it available to teachers. Teachers' feedback will be sought in the future.

## REFLECTION AND CONCLUSION

Our design experience reflects the complexity of design. We have encountered multiple challenges over the entire process. One challenge is the timeline of our design cycle. Because designing the teacher's dashboard is situated in the larger project of Alien Rescue, the logistics of how and when Alien Rescue is used in schools constrain when we can test our design ideas in the classrooms. Alien Rescue is used as part of space curriculum unit in a spring semester by local school teachers once a year. We need to wait till teachers to begin their AR implementation before we can get feedback on our design ideas of the teacher's dashboard. The design team usually came up with design ideas in a fall semester and then tested the prototypes in the following spring semester. That is why our design process took five years as each cycle from idea generation to implementation took about one year. Another major challenge is that our design and development team are made up of graduate students majoring in learning technologies and the majority of the members do not have the necessary technical skills. Therefore, it takes time to develop adequate technical skills to translate the conceptual ideas to an actual product. While we came up with many ideas during the initial brainstorming phase, we had to prioritize what was important for the stakeholder and what we could accomplish technically. For example, we focused on displaying the three aspects of Alien Rescue program: probe design, alien placement, and notebook and left other aspects (e.g., map of space station, topics most visited in databases, management functions such as filtering and sorting, deleting duplicate students, rearranging displaying columns as listed in Appendix B) for future consideration. However, this design and development process presents an excellent learning opportunity for these graduate students who are motivated to learn and apply the design and technical skills in creating a real-world application and get better prepared to be future instructional designers and technology developers (see more description in Liu et al., 2014).

Although these challenges are unique to our case, our design process reflects some important characteristics that can be useful to other designers and developers. An important aspect of design is that it is an iterative process aiming to understand human problems and attempting to find creative solutions to address the problems (Brown, 2009). Our design case is such an example. The goal of our design is to tackle the problem of enabling teachers who use AR project to view information their students have entered easily and just-in-time. Our design process from idea conceptualization to implementation of the teacher's dashboard have highlighted two factors of importance:

(a) design and implementation is really a *continuous* iterative process as outlined and emphasized in the design thinking literature (Brown, 2009; https://dschool.stanford.edu/) and (b) it is necessary to get feedback from the key stakeholders (sixth-grade teachers for whom this dashboard is designed for) at *every* stage. Both formal (e.g., surveys in this case) and informal (e.g., talking to teachers while we were making classroom observations) are valuable to us. Although we have started with a low fidelity medium for prototyping using paper and Google Slides, higher fidelity prototypes using Axure RP are more useful given its interactive nature. Showing teachers prototypes, even if the prototypes are still preliminary, helps us gain valuable insights as to what will or will not work for the end users. In our view, these two factors are essential to the success of a project.

Apart from being designers, we are also researchers and have research interests. In fact, the larger project Alien Rescue that this design case is part of is our R&D project. We realize that our research interests may not necessarily align with what our end users' desire. For example, displaying leaderboard, gamification ideas mentioned in the design phase are of less interest to teachers, but those are our research interests. One takeaway is we need to focus on what our end users' needs first. In addition, teachers are usually busy and will not have a lot of time to provide detailed feedback. A lesson we have learned is that we, designers, need to ask very specific questions (e.g., listing which feature(s) we think the teachers want or showing visually how specific screens of the dashboard may look like). Visual representations allow teachers to quickly tell us what they think will or will not work. We have also learned observing how teachers use the dashboard in the classrooms and then following that up with questions can provide a lot of insights as to what is working, what is not, and the issues we need to address. We used both online surveys and classroom observations to get feedback on our designs. We observed three to five teachers' use of Alien Rescue in their classrooms every year. We kept continuous communications with teachers to seek their feedback. Surveys provided some high-level information and observing teachers' actions in the classrooms and then asking them questions provided more insights. We also found sometimes end users might overlook a new feature we implemented. For example, we added a new feature of "Add budget" under Actions as shown in Figure 13 in the first iteration of the implementation phase, and yet some teachers still requested this feature. In order to draw attention to the new features especially for those who have used AR previously and may overlook newly added features, having an accompanying professional training module highlighting newly added features would be a good idea. At this point, we have implemented this training module delivered online.

In summary, through this experience of designing the teacher's dashboard as an accompanying tool to Alien Rescue project, we, the designers, put our knowledge and skills of

instructional design and learning technologies into practice. Our experience highlights that design is a complicated endeavor and it is not linear but iterative, and revisions can occur at every stage.

## ACKNOWLEDGEMENT

## REFERENCES

Belland, B. R., Glazewski, K. D., & Richardson, J. C. (2008). A scaffolding framework to support the construction of evidence-based arguments among middle school students. *Educational Technology Research and Development, 56*(4), 401–422. https://doi.org/10.1007/s11423-007-9074-1

Bogard, T., Liu, M., & Chiang, Y. H. (2013). Thresholds of knowledge development in complex problem solving: A multiple-case study of advanced learners' cognitive processes. *Educational Technology Research and Development, 61*(3), 465–503. https://doi.org/10.1007/s11423-013-9295-4

Boling, E. (2010). The need for design cases: Disseminating design knowledge. *International Journal of Designs for Learning, 1*(1).

Brown, T. (2009). *Change by Design: How Design Thinking Transforms Organizations and Inspires Innovation*. New York, NY: Harper Collins Publishers Inc.

Devlin, J., Chang, M. W., Lee, K., & Toutanova, K. (2018). Bert: Pre-training of deep bidirectional transformers for language understanding. *arXiv preprint arXiv:1810.04805*.

Howard, C. D., Boling, E., Rowland, G., & Smith, K. M. (2012). Instructional design cases and why we need them. *Educational Technology*, 34-38.

Ge, X., & Land, S. M. (2004). A conceptual framework for scaffolding ill-structured problem-solving processes using question prompts and peer interactions. *Educational Technology Research and Development, 52*(2), 5–22. https://doi.org/10.1007/BF02504836

Liu, M., Horton, L., Lee, J., Kang, J., Rosenblum, J., O'Hair, M. & Lu, C. W. (2014). Creating a Multimedia Enhanced Problem-Based Learning Environment for Middle School Science: Voices from the Developers. Interdisciplinary *Journal of Problem-Based Learning, 8*(1). Available at: http://dx.doi.org/10.7771/1541-5015.1422

Liu, M., Kang, J., Lee, J., Winzeler, E. & Liu, S. (2015). Examining through visualization what tools learners access as they play a serious game for middle school science. *Serious Games Analytics: Methodologies for Performance Measurement, Assessment, and Improvement* (pp. 181–208). Switzerland: Springer. https://doi.org/10.1007/978-3-319-05834-4

Liu, M., Lee, J., Kang, J. & Liu, S. (2016). What we can learn from the data: A multiple-case study examining behavior patterns by students with different characteristics in using a serious game. *The Technology, Knowledge and Learning journal, 21*(1), 33–57. http://link.springer.com/article/10.1007/s10758-015-9263-7. https://doi.org/10.1007/s10758-015-9263-7

Liu, M., Yuen, T. T. Horton, L., Lee, J., Toprac, P. and Bogard. T. (2013). Designing technology-enriched cognitive tools to support young learners' problem solving. *The International Journal of Cognitive Technology. 18*(1), 14-21.

Pan, Z., Chenglu, L., Wenting, Z., Liu, M. (2021, April). *The development of an automatic text classifier enhanced dashboard in supporting teacher's facilitation of virtual problem-based learning activities*. Paper presented at the annual conference of *American Educational Research Association* (AERA). Orlando, FL.

Savery, J. S. (2006). Overview of PBL: Definitions and distinctions. *Interdisciplinary Journal of Problem-Based Learning, 1*(1), 9-20. https://doi.org/10.7771/1541-5015.1002

# APPENDIX A

## Notes on Evaluating Dashboards on the Market

**From Khan Academy:**

Energy points for the class–seems to be a pointed line graph with zero in the middle and positive above and negative below. It's updated every minute, so a teacher could just watch it. If we were doing something like this for AR, how would it work? You could take a stage that kids are in (one of the four problem-solving stages), designate tools that they should and shouldn't be using, and then the energy bar reflects the average of where kids are spending their time in the classroom. Is this helpful?

One major difference is that our content isn't linear, and we don't want it to be. We have identified certain positive patterns of interaction with the environment based on previous studies, but we don't want to be too prescriptive. With just log data of tool use patterns alone we could get a lot of false positives and false negatives as far as kids who are doing fine and needing help. Specific definitions of what a struggling and a thriving student look like are still lacking. Could this be a future direction for LA?

**From Hapara.com:**

Teachers can see all students on a page and what documents they have in their folder (they can choose to see 3, 5, 10, 15, etc. at a time). We could do this with the probe justifications and rationales. Can sort students by first or last name, class group, ascending/descending order. You can also choose between viewing students in rows or columns. You can assign students a color to make them stand out. You can search for keywords within the document (as well as for students if a big list). So, teachers could search for an Alien or planet name to see which kids are working on it, etc. Show timestamp for submitted text. Manual refresh button. Button to message kids within the system (can use Message Tool) right there next to their name. Could have notes, justifications, and rationales in the same page, but differentiated visually.

**From econsultancy.com:**

**Toutapp:**

Could word clouds be a cool way to visually capture class writing activity? You could do a whole class, all subjects one; single student; single subject (notes titled Akona). With a single student, it could tell you what they've learned. With a single subject, you can see what facts are most commonly learnt among the students. For the general one, you can get a feel for how the whole class is doing, and whether students are taking the writing tasks seriously.

**Lancaster Bingo Company:**

The Order Summary format could be borrowed to create a student summary with things like notes written, probes launched, recommendations submitted, budget, etc. You could even break things down further into notes according to category, planet notes vs. alien notes, for instance. You could show the student against the class average.

I still like the player shapes idea from that one article if we use a line graph to show activity.

**From Cranium:**

We might also be able to do word clouds with the titles of the pages most frequently accessed in a given database. Would be really good for Concepts, Solar System, and Alien DB.

**From Airbnb:**

Progress bars are really salient visually. How can we incorporate them into the TsDB? Aliens placed would be the obvious one, but it won't be very interesting for the first few days. The other ones don't have a "complete" state, so it's hard to do a progress bar.

**From Statisti.cs:**

The multi-level pie chart is an interesting idea, but they're not the most intuitive visually. Would have to think about how best to use it, if at all.

**From Wave:**

Would we like teachers who are long-time users to be able to compare classrooms over time? Or actually, compare different classrooms simultaneously would be even better. The stacked line graphs (showing player shapes) would be great for that.

**From Trendkite:**

A map that shows room activity by the size of circles = fun!

From Chartbeat: The vertical lines with the colored circles would actually be a good way to show where a student falls compared to the class as a whole on a certain measure.

# APPENDIX B

## Outline of Desired Features to Consider in the Dashboard

- Tabs
  - My Classes (multiple classes as a teacher typically teach 5-6 classes)
  - My Class (one single class)
  - Manage Students–add/delete students, place into groups, send a message, take screenshot, adjust budget, sort to find a student
  - Student Name
  - Can have multiple classes open at a time
- Management capabilities
  - Message students
  - Give students badges
  - Take a screenshot of students' screen?
  - Adjust budget
  - Search for names and keywords within students' text
  - Sort students
  - Place students in groups
- Overall snapshot of class activity
  - Map of space station that shows where students are
  - Aggregate Action Shape, plus capability to separate into groups
  - Topics most visited in Databases
    › Alien
    › Solar System
    › Concepts
    › Missions
  - Total notes created
    › leaderboard with top 10 (based on character/word count?)
    › Word cloud for notes–general one automatically generated on homepage, but teachers can create new ones for specific note titles
  - Total probes created
    › leaderboard with top 10 (based on % new information)
    › Word cloud for probe justifications
    › Breakdown of probe destinations by associated alien (or none)

› Probe errors
  » % of instruments
  » Broken down by cause
- Total aliens placed
  › leaderboard with top 10 (taking accuracy into account)
  › Word cloud for justifications
- Activity feed that shows notes created, probes designed, and recommendations submitted in real time (with timestamp)

- Overall snapshot of individual's activity
  - tools currently in use (like Hapara's open tabs)
    › active
    › time opened
  - Action Shape of tool use
  - budget
  - number of notes
  - number of probes
  - aliens placed
- Notes created
  - number of notes, broken down by category
  - full content of notes
  - date/time modified
  - keyword analysis?/ word cloud
  - search feature
- Probes created
  - number of probes created and launched
  - breakdown of probe destinations by associated alien (or none)
  - full content of probes–all instruments, cost, destination, timestamp
  - error messages–with explanations as to cause
- Aliens placed
  - correct/incorrect score
  - full text, time stamp
  - Time taken to write justification

# APPENDIX C
## Discussion Points Based Upon Interactive Prototypes

**Monitoring Tools**

- What additional functionality can you suggest for this page?
- What additional visualization can you suggest for this page?
- Other comments:

**Grading Tools**

- Do you have a preference for the compacted or expanded versions?
- Would you like to suggest an alternative way to present the information? (Include mockups)
- What additional functionality can you suggest for this page?
- What additional visualization can you suggest for this page?
- Other comments:

**Class Activity**

- Would you prefer to see the widgets on one page or (two) separate pages?
- If you prefer to see the widgets on one page, would you like to suggest an alternative way to present the widgets?

- How would you divide the widgets into pages? What names would you give the pages?
- How should we determine a student's standing on the leaderboard for notes?
- Conversely, how should we determine if a student is exhibiting a red-flag behavior regarding notes?
- How should we determine a student's standing on the leaderboard for probes?
- Conversely, how should we determine if a student is exhibiting a red-flag behavior regarding probes?
- How should we determine a student's standing on the leaderboard for alien placements?
- Conversely, how should we determine if a student is exhibiting a red-flag behavior regarding alien placements?
- What additional functionality can you suggest for this page?
- What additional visualization can you suggest for this page?
- Other comments:

**Print Report**

- What additional functionality can you suggest for this page?
- Other comments: