The Rex virtual experiment platform: Design, implementation, and situational interest

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Introduction

Laboratory-based learning is one of the most vital components of scientific education (Ma and Nickerson 2006). However, traditional "hands-on" high school science laboratory experiments in the United States have several challenges for teachers to overcome. Many high school laboratory experiments are "cookbook-style" and uninspired (Modell and Michael 1993; McComas 2005), scientific practices and the scientific content being taught are not always integrated together effectively despite recent reform efforts (NRC 2006, 2012, 2013), and laboratory experiments are not always interesting to students nor relevant to their daily lives. These issues are exacerbated by contextual factors present in many high schools. For example, time in the classroom is limited, whereas experiments take time to plan, set up, and conduct. The time it takes to complete an experiment can compete with the precious time required to prepare students for end-of-course and other standardized tests. Further, teachers may have limited experience with various scientific methods, especially cutting-edge research techniques. There are also financial limitations, which usually preclude the use of scientific equipment due to purchase expense, space, and maintenance (Gomes and Bogosyan 2009). Finally, in the case of biology, there are often restrictions on study organisms; for example, experiments involving vertebrates are not allowed in many high schools.

One way to address many of these limitations is the use of non-traditional laboratory experiments (Ma and Nickerson 2006; Brinson 2015). These can generally be broken down into two types: "virtual" experiments, which involve simulated, physically non-existent equipment, and "remote" experiments, which involve real, physical equipment that the user operates remotely (Ma and Nickerson 2006; Brinson 2015; Childers and Jones 2015; Guerra-Varela et al. 2016; Heradio et al. 2016). Non-traditional laboratories not only reduce costs, they provide the additional benefits of availability (rather than being restricted to a particular time or a particular physical location), accessibility (especially for the handicapped), and safety (Gravier et al. 2008; Heradio et al. 2016). A recent meta-analysis of 56 studies found that non-traditional laboratories can be quite effective compared to traditional-learning laboratories: 89% of studies reported equal or higher learning outcomes in non-traditional laboratories relative to traditional laboratories (Brinson 2015).

A sub-category of virtual laboratories is the online virtual science experiment. Online education in the US has undergone dramatic growth, rising from 45,000 K-12 students in 2000 taking an online course to more than 3 million students in 2009 (Horn and Staker 2011); this growth has been accompanied by the continued growth and popularity of home schooling, with ~2 million home-schooled students in 2011 (Christensen et al. 2008). It has been projected that by 2019, 50% of high school courses will be online, and that the majority of these courses will actually be taught locally in mainstream high schools (Christensen et al. 2008). Thus, there is a real need for effective online resources to support students' engagement in scientific practices. In recent years, many online programs have been developed to teach science at the high school level. Online science education can range in interactivity from video-recorded lectures or simple animations, to "click-and-learn" interactive demonstrations, to educational video games, to "virtual" laboratory experiments that involve performing "experiments," collecting data, and answering questions (Liu et al. 2001; Guerra-Varela et al. 2016). Examples along the entire range of this spectrum can be found on the Howard Hughes Medical Institute's BioInteractive website (http://www.hhmi.org/biointeractive/). Some recent programs that provide a "virtual" feel to engaging in scientific research are quite diverse in topic, including nanotechnology (Tarng et al. 2017), ecology and biodiversity (Hardisty et al. 2016), zebrafish genetics (Guerra-Varela et al. 2016), and astronomy (http://www.golabz.eu/lab/galaxy-crash).

However, many online programs do not engage the learner in real experiments that are performed by real scientists. Often, virtual labs present an "ideal world" using simplified conditions and perfect data that conform neatly to the hypotheses—they do not include a realistic simulation of an actual scientific investigation replete with the potential for noise, errors, and complex interpretations of results (Chen 2010). To provide a more authentic experience that teaches about the process of science in addition to scientific skills and concepts, we developed an online resource to immerse students in an actual scientific investigative process; students gain experience planning an experiment, collecting and analyzing real data, and participating in the entire process as a team. Our program, Rex ("**R**eal **ex**periments"), is a "virtual" web-based biological science experiment platform, hosted by real scientists, and uses actual lab experiments that generate real data for students to collect, analyze, and interpret. The Rex platform was designed to address several of the previously discussed limitations teachers often face in high school biology laboratories, including time, finances, experience, and restrictions on live study organisms. Rex includes seven neuroscience-based experiments that use zebrafish and rats as model systems to study the effects of drugs such as tetrahydrocannabinol (THC - the active compound in marijuana that gets one "high"), caffeine, alcohol, and cigarette smoke.

We created Rex to accomplish several overarching goals. First, Rex is intended to increase interest in science. Therefore, we focus on topics in pharmacology, a subject that high school students tend to find interesting and relevant (Sandoval 1995; Jenkins and Nelson 2005) and that can be used to enhance basic biology and chemistry content knowledge (Schwartz-Bloom and Halpin 2003; Kwiek et al. 2007; Schwartz-Bloom et al. 2011). Specifically, through both its focus on drugs and the brain as well as the use of a web-based platform, Rex is designed to support students' *situational interest* in science. Situational interest (SI) is a category of student interest that emerges in response to environmental factors (Renninger and Hidi 2016) and can precede and facilitate more enduring and deeper *individual interest* (Linnenbrink-Garcia et al. 2013; Renninger and Hidi 2016). Individual interest is a strong predictor of career choices and is also related to academic engagement and achievement (Schiefele 2009). Second, Rex was designed to engage students in the same authentic scientific process that is used by scientists in the real world, without actual physical "hands-on" involvement. Third, Rex was designed to maximize accessibility to lab experiments as a powerful resource for teachers. Once the platform undergoes final revisions, it will be released online to teachers free of charge.

In this paper, we document in detail the Rex web platform, and we describe our pilot implementation of Rex in 12 high school biology classrooms in North Carolina. We discuss teacher recruitment and training, classroom visits for implementation observation and technical support, the various technical challenges encountered, and we summarize our post-Rex feedback from teachers and students. In addition, we assessed students' SI to determine whether the Rex experiment captured students' attention, and whether it was an enjoyable and meaningful experience.

Methods and Rex Design

The Rex project involved 1) designing and building the Rex platform, 2) performing the actual experiments to generate the real data for the users to analyze, 3) hiring graduate students to serve as the real scientists, 4) creating videos of the scientists performing the experiments and communicating with high school students, 5) implementing Rex in high school biology classrooms, and 6) assessing student interest in the program. Each of these features is presented below.

Rex—program architecture

Rex is a multi-component interactive online platform built with a cloud-based, distributed architecture (Fig. 1). The main Rex application is a client-side JavaScript application that runs in a student's standard web browser. This application is served from, and interacts with, the Rex server-side application which is hosted on a cloud application platform (Heroku). Both client-side and server-side applications also interact with several other cloud services for key functionalities: 1) a secure database platform that stores user-generated data and manages account information and authentication (Firebase), 2) a file storage and synchronization service for downloadable documents that is also integrated with collaborative spreadsheet software (Google Drive/Sheets), and 3) a web storage service for the data image files from experiments (Amazon S3/Cloudfront). We chose Google Drive for the ease of organizing and editing the downloadable files; we chose Amazon S3/Cloudfront for storage of the data files because it is optimized for fast downloads of static images. The website is designed and supported for the Chrome browser.

Rex—general website design

The Rex platform presents seven experiments individually (Table 1) and also grouped into five themes: 1) Learning and Memory, 2) Effects of Alcohol on Neurons, 3) Neuromast Development, 4) Gene Expression, and 5) Animal Models for Human Behaviors. Once users choose an experiment, they are guided through the experiment by a "navigation menu" and by the scientists via YouTube videos (see below). The website is organized in the same way a real experiment is conducted, starting with minimal background reading, and then continuing with 1) hypothesis formation, 2) variable selection (e.g., dose, time, age), 3) dilution calculations, 4) real data collection, 5) data analysis, 6) statistical analysis, and 7) data presentation (the creation of graphics). Last, a series of questions about the experiment are included to assess critical thinking skills, providing the teacher with information about the student's understanding of the experiment.

The software interface consists of a main panel in the center, a navigation menu on the left, and a collapsible "Notebook" on the right. The main panel (Fig. 2) contains 1) short text sections (e.g., background, statistics tutorial), 2) videos of the scientists, 3) questions to answer, and 4) data generated from the experiments.

The navigation menu on the left (Fig. 3) can be used to jump to any point in the experiment, and the Notebook (opening on the right; Fig. 3) is where students answer questions posed by the scientists, enter and graph their data, and answer the critical thinking questions. We designed the interface to give students control over their own progress, so that it would be flexible to a range of different abilities (Wang and Yang 2005): in addition to the navigation menu and video controls, we provide text-over definitions for keywords, and optional links to more detailed background information and tutorials.

The Rex experiments

The seven Rex experiments are based on previously published neuroscience studies (Table 1). The experiments were chosen to range from very simple design and implementation to more technology-driven and sophisticated implementation. The experimental organisms are zebrafish (*Danio rerio*) and rats (*Rattus norvegicus*), which are well-established, simple models for the effects of drugs on humans (Iannaccone and Jacob 2009; Guerra-Varela et al. 2016).

Members of the principal investigator's lab performed the experiments (except the spatial learning and gene expression experiments, which used actual data from the respective published studies) to generate real data that would eventually be stored on the cloud servers for student access. Data from all experiments were collected as images (JPEGs) or video clips (MP4). Thus, high school students access the same forms of data as would the scientists, providing students with an authentic research experience, minus the "hands-on" component.

The Rex scientists and filming

A key feature of Rex is the series of short video clips of real scientists performing the experiments and "interacting with" the high school students. Rather than choosing older and established scientists for the video presentations, we felt it was important to maximize relatability for high school students and provide role models. Therefore, we recruited doctoral graduate students in basic sciences (e.g., pharmacology, biochemistry, cell biology) from our university (Figs. 2, 4). Of the 10 scientists, six were women and four were underrepresented minorities. Pairs of scientists performed an experiment, and at least one of each pair was either female or an underrepresented minority. In this way, we hoped to combat stereotypes of scientists so high school students could see that scientists are really "everyday people." Working closely with the scientist graduate students, we created scripts for video segments to cover the background, hypotheses, variable selection, dilution calculations, data collection, and data analysis. The graduate students used the scripts as guides but ad-libbed frequently. The video segments were filmed in our lab, and included demonstrations of the actual equipment used in the experiments. After filming, the video segments were edited with Adobe Premiere and uploaded to YouTube.

The inclusion of the videos was designed to provide students with an active role in the experiment, despite the lack of a physical hands-on component. To encourage interactivity, we made the video segments short (~1-2 minutes), and each video ends with the scientists posing a question to the students, and telling the students to write their answer in their Rex Notebook (see below). To reinforce the questions, we placed a "red box" underneath the video window (Fig. 2) that contains the question posed by the scientist, and in some cases we provided instructions on how to enter the information (e.g., data) in the Rex Notebook. In addition to questions, the scientists ask the students to choose experimental parameters such as drug dose, age of animals, etc.. Students select their choices from a range that is provided (Fig. 4) and pop-up alerts let them know if the choice is not proper (e.g., a dose that is too high might be toxic to the study animal). Wherever possible, we integrated "choice" and "ownership" into the virtual experiment; other studies have shown that these characteristics result in more engaged, focused, and immersed participants (Childers and Jones 2015)

Students can replay any video anytime, and the videos do not have to be viewed in order, although the navigation menu buttons on the left change color permanently once the student has viewed a video. In this way, the student can stop, and then later continue at the appropriate place, without having to search through the whole navigation list. A complete narrative script for students who have difficulties with spoken English was included in the supporting teacher resources within the Rex website.

The Rex Notebook

The Rex Notebook (Fig. 3) is used in the same way a lab notebook is used by scientists. Every piece of information about the experimental design and data collection is recorded into the Notebook. In response to questions posed by the scientists, the student clicks in the “red box” under the video, which opens the Notebook (to the appropriate section). The cursor is conveniently active in the field where the student should record the answer. The Notebook is automatically saved each time it is closed. In the initial stages of the experiments, students write their own hypotheses and dependent measures into their Notebook (even if these are not the specific ones that are used in the experiment). Then the scientists discuss what the best hypothesis would be for measuring a response, and the students rewrite the hypothesis in their Notebooks. The same procedure is used for students to identify their dependent and independent variables. The “back and forth” approach allows the students to be creative and involved in the experimental design, even though the experiment has actually been performed previously.

During the data collection phase, students take on the same role as the scientists. Using the actual images or videos generated in the real experiments, students measure responses and record their data in data tables within a Google Sheets spreadsheet linked inside the Notebook. The spreadsheet is generated automatically the first time the student opens it. To the best of our knowledge, the individual-centered automatic creation of spreadsheets is a novel use of Google Sheets. Once an individual “opens” a spreadsheet, the spreadsheet remains specific to that individual and it is then stored on Google Drive. If the individual opens a spreadsheet for another experiment, a separate spreadsheet specific to that that experiment is created. (As noted in the Results, we pre-loaded data tables with some of the data to reduce the number of observations that students would be required to measure during a class period.)

Tutorials are provided to help students perform data analysis, statistical analysis, and data graphing in the Notebook. After students perform their statistical analysis, they write in the Rex notebook their answers to a series of critical thinking questions about the experiment. As described below, each student’s Notebook can be viewed by the teacher in real time on his/her own computer to determine how far the student has proceeded, whether the student has skipped items, etc..

Teacher recruitment and training

We recruited seven Biology teachers from four high schools in a single school district in North Carolina. The subject school district is under-resourced with an average of 58% high school students enrolled in free & reduced lunch programs as of 2016. The teachers consisted of five females and two males, ranging in age from 24 to

53; they had a median 6 years' high school teaching experience, ranging between 2 and 28 years. All teachers had Master's degrees. Prior to the start of the Fall 2016 semester, we provided a full day of training to teachers on how to use Rex. They worked through several of the experiments in small groups, modeling what their students would do later. The teachers provided helpful feedback so that we could edit features and include additional resources for their classrooms prior to launching the pilot-test. In the final Rex implementation, online tutorials will take the place of an in-person training workshop.

Teacher dashboard

Teachers access the Rex program through their own portal, which provides them with enhanced functionality: teacher accounts display the student interface, but also include class management tools and additional downloadable resources for each experiment. Teachers can monitor from their accounts the progress of each student in each experiment, and they can observe each student's Notebook in real-time. The experiments are also flexible according to each teacher's needs. While a full Rex experiment would take about 3 hours of class-time, teachers can adjust experiments as needed and skip certain sections (e.g., statistical ANOVAs, graphing), assign some sections as homework, and/or do some sections themselves to show students at a later date (such as graphs of the collected data).

Technical requirements for Rex access

Prior to implementing Rex in the classrooms, we had to ensure that the web-based program would work smoothly given restrictions in the schools' internet security firewalls. Typically, public high schools "blacklist" most URLs (web addresses) that are not supported by the school system so that students are unable to access them within the school internet, typically including many portions of YouTube.com. Thus, we provided the subject school district's Information Technology (IT) department the URLs of all the Rex YouTube videos. This allowed all Rex-related web resources to be allowed through the firewall (i.e. "whitelisted"). Secondly, we required students to log into YouTube with their school-provided user credentials prior to logging into Rex. [This was required by the subject school district's IT department, but may not be a universal requirement.] Other web-related features contained in Rex, including Google Sheets and Google Drive, did not require any whitelisting in the subject school district's system.

Rex implementation in the classroom

Collaboration is an important feature of scientific research, so Rex was designed to foster collaborative work within the classroom. Ideally, the program can be used in groups of 2-4 students, but each student should have their own laptop for data collection, entry into their Rex Notebook, and to answer the critical thinking questions. Most students used school-provided Chromebooks or Macs; we supplemented classrooms with new Chromebooks if they did not have enough.

We pilot-tested Rex in 12 biology classrooms, which consisted of 263 students participating in the following courses: Biology (Standard, Honors and AP), Anatomy/Physiology, and Forensic Science. We asked teachers to implement at least one Rex experiment in their class(es) during two consecutive 90-minute class periods. Some teachers realized before using Rex that their standard classes might not have the reading and math skills to work through an entire experiment and suggested we offer an "abridged" version of their Rex lab to complete in one hour (see comment in Results).

Teachers chose experiments that supported their current course content. To determine how students and teachers actually used the program, 1-2 members of the research team served as "observers" by visiting each classroom while using Rex. The observers also provided technical support during their visits to the classrooms. After the experiment was complete, the observers assigned scores ranging from 1 (poor) to 5 (excellent) in the following categories: technology issues, teacher preparedness, teacher engagement, class management, and class overall score. If two observers were present, average scores were calculated. An overall implementation score was also calculated by taking the mean of teacher preparedness, teacher engagement, and classroom management; an overall observer score was calculated by taking the mean of teacher preparation, teacher engagement, classroom management, and technology scores.

Situational interest (SI) and student feedback

For the purpose of assessing SI, we included a brief survey at the end of each experiment (Online Resource 1). Students were given the option of opting out of the survey. The survey was developed and validated by Linnenbrink-Garcia and her colleagues (2010). Specifically, we used a composite indicator of SI, ($\alpha = .96$), which included 12 items assessing 1) triggered-SI (i.e., the extent to which the Rex experiments grabbed students' attention, excited them), 2) maintained-SI-feeling (i.e., the extent to which the content taught during the Rex unit was enjoyable), and 3) maintained-SI-value (i.e., the extent to which the content taught during Rex was viewed as important or valuable). After completing the SI items, students responded to two open-text questions asking what they liked most and least about the experiment.

The student could only access the survey after having submitted their Rex Notebook to the teacher at the completion of the experiment. Ideally the survey would take place in-class at the conclusion of the experiment, but in some cases it occurred later. Survey responses received more than 6 days after the Rex experiment were not included in the analyses (see Results). The SI answers were analyzed using a multi-level modeling approach using the lme4 (Bates et al. 2015) package in R (R Core Team 2017) to account for the nesting of students' in class. These multi-level models were supplemented using Analysis of Variance (ANOVA), also using R, to investigate differences among sub-groups of teachers. We administered a separate anonymous online survey to obtain student demographic data (e.g., gender, race/ethnicity), which are reported at the class level.

Teacher Feedback

At the completion of each Rex lab, we administered a feedback survey to teachers (Online Resource 2). The teachers provided ratings of students' overall ability to engage in Rex content, as well as their own confidence and preparedness in using Rex in their classrooms. Demographic information (e.g., gender, race/ethnicity, age, and teaching experience) was collected from all teachers.

Results

There were 263 high school students who participated in Rex experiments. They consisted of predominantly underrepresented minorities; demographic details are presented in Table 2. Of the seven possible

Rex experiments, teachers implemented four of them across the 13 classes (12 physical classrooms; one teacher ran a second Rex experiment in one of her classes; Table 3 and Online Resource 3). The most frequently performed experiment was *Stress and Anxiety: The Novel Tank Test*. Three experiments (*Spatial Learning: The Morris Water Maze*, *Gene Expression: Cigarette Smoke*, and *Gene Expression: THC*) were not performed.

Classroom Observations

At least one member of the research team attended each class that was implementing Rex to observe and provide technical help. Classes were rated on a 1-5 scale for technology issues, teacher preparedness, teacher engagement, and classroom management, to generate an overall class score (see Methods). Scores ranged from a high of 5.0 to a low of 2.2, the latter reflecting a lack of teacher preparedness or technology problems (Table 3).

Most of the technology issues encountered were related to internet connectivity, including state-wide internet outages and slow internet connections. Slow internet connections led to occasional problems with registration of student login emails due to Rex's cloud-based distributed architecture. Rex performed smoothly on the student Chromebooks and Macs, and any rare intermittent issues were usually resolved by refreshing the browser or rebooting.

Most teachers were able to finish Rex within two 90-minute class periods. Some teachers wrapped up in a short session on a third day. As highlighted in the Methods, one teacher asked us to modify the Rex implementation to one hour for her standard classes that were functioning at lower reading and math levels. For this class, the first part of the Rex experiment (up to data collection) was completed as a classroom activity rather than in small groups, with videos projected on a whiteboard. Subsequently, the teacher guided the students through the portions of the experiment that required reading. While the students were able to complete the experiment in one hour, we did not feel they had the same depth of experience as those engaging in the complete exercise.

Student Feedback about Rex

The survey to obtain student feedback and SI (Online Resource 1) was included within the website after students submitted their Notebooks to their teachers. Most students (~70%) submitted their surveys in-class, either the day they completed Rex or the next day. Approximately 30% of students submitted their survey outside of class. Additional information about the exclusion criteria of survey responses is provided in the section below on Assessment of Situational Interest (part of the survey).

When queried what they liked most about Rex, the most common positive comments about Rex content focused on being involved in the experimental process, the relevance of Rex to the students' everyday life, and an interest in the study organisms used (Online Resource 4). Among positive comments about the technical aspects of Rex, students liked being able to collect actual data, learning to use spreadsheets, the "clear," "easy-to-follow" instructions and videos, and the interactivity of the platform. When queried what they liked least about Rex (Online Resource 4), the most common negative content comments included implementation was "boring" and the scientist hosts were "awkward". The most common negative technical comments revealed that students felt there was too much data to collect, and that they would have preferred a more physical hands-on experiment. Since we received the feedback about overwhelming data collection early in the project, in subsequent classes we prefilled some of the data into the data collection spreadsheets. Students were still able to sample and collect data, but they appeared much more engaged.

Assessment of Situational Interest

Of the 263 students participating in Rex, we received 202 surveys. Fourteen surveys were excluded from analyses because students 1) declined to participate, 2) did not complete the survey, 3) completed the survey more than 30 days after using Rex, or 4) responded in a manner that suggested they were not reading the questions. Additionally, 22 surveys were from students in a classroom that did two Rex experiments; these 22 responses are included in analyses unless otherwise noted.

Overall, students reported a moderate level of SI as a function of participating in the Rex experiments (M = 3.18, SD = 0.91). More specifically, 68.1% of students responded above neutral (i.e., had average scale values greater than 3.0 on a 5-point scale), with 19.7% of students reporting that they agreed or strongly agreed (i.e., had average scale values greater than 4.0 on a 5-point scale) that the content taught as part of the Rex experiments was meaningful to them and exciting and that doing the Rex experiments was exciting and engaging (Online Resource 5).

To consider whether students had similar levels of SI in response to participating in Rex across classes, we conducted a multi-level analysis comparing levels of SI across the 12 classrooms. For this analysis, we only included students' SI for their first experience with Rex as the outcome variable (i.e., we eliminated the 22 responses from students in one class completing a second Rex experiment). For these models, we tested a simple "null" model with no predictor variables in order to establish the proportion of variability in the outcome (SI) that was attributable to the class level. Results indicated that 19.7% of the variance in students' reports of SI could be accounted for by class, suggesting that there were meaningful differences in SI between classes (Fig. 5). To further investigate the class differences, we considered whether the classroom variables of 1) an observer score (the mean of teacher preparedness, teacher engagement, classroom management, and technology scores), 2) class level (standard, honors, AP), and 3) subject area (biology, anatomy/physiology, forensic science) might explain the differences in SI. Notably, there were no significant differences in SI as a function of implementation/technology (β[1] = -.07, p = .666), class-level (β = -.10, p = .495), or subject area (anatomy v. biology, β = .34, p = .520; forensic science v. biology, β = -.20 p = .728). Students exhibited similar levels of SI regardless of the type of class they were in or how Rex was implemented in their classrooms.

To further explore the observed classroom differences, we considered whether there were differences based on the teacher (several teachers taught more than one class, thus the analyses above provide information at the class level, not the teacher level—see Online Resource 3). However, teacher and Rex experiment were confounded, as most teachers only conducted one Rex experiment and two experiments were only conducted by one teacher (Online Resource 3). Thus, for these analyses, we compared students' SI from the two teachers[2] who completed the novel tank experiment (Teachers 5, and 7, see Table 3) as well as for the three teachers who completed the startle response experiment (Teachers 1, 2 and 8, see Table 3) using ANOVA. For these models, the SI composite was the outcome

[1] The reported coefficients are standardized (for continuous variables, both independent and dependent variables were standardized such that the M = 1 and SD = 1; for dichotomous or dummy-coded variables, dependent variables with M = 1 and SD = 1 were used).
[2] Teacher 4 also completed the novel tank experiment. However, due to problems with data collection, responses were only available from one student. Thus, the data from Teacher 4 were not included in these analyses.

variable and teacher was the predictor variable. These analyses included data from either the first or second experiment (e.g., the novel tank task was the second experiment completed by students in Teacher 5's class). There were statistically significant differences in students' SI as a function of teacher for the novel tank experiment (F (1, 50) = 8.83, η = 0.150; p = .004) such that students in Teacher 5's class had significantly lower SI (M = 2.86, SD = 1.07) relative to those in Teacher 7's class (M = 3.55, SD = 0.60). However, there were not any statistically significant differences in students' SI as a function of the teacher for the startle experiment (F (2, 74) = -.657, η = 0.02; p = .657. Notably, when we removed Teacher 5 from our previously reported multi-level models, there was no longer any variation in SI at the class level (ICC = 0.00), suggesting that the inclusion of data from students in Teacher 5's classes likely accounted for the observed classroom-level variation in SI.[3]

Finally, we also considered whether there were differences in SI as a function of the REX experiment. For these analyses, we used ANOVA with the SI composite as the outcome variable and the Rex experiment type (novel tank, 3-chamber, startle response, neuromast viability) as the predictor variable. We only included data from students completing the first experiment if they performed two. There were statistically significant differences based on Rex experiment type (F (3, 184) = 7.62, η = .11 p < .001), such that students who completed the 3-chamber experiment had statistically significantly lower SI (M = 2.65, SD = 0.93) than students who completed the other three experiments ($M_{novel\ tank}$ = 3.27, $SD_{novel\ tank}$ = 0.88; $M_{startle\ response}$ = 3.37, $SD_{startle\ response}$ = 0.83; $M_{neuromast\ viability}$ = 3.42, $SD_{neuromast\ viability}$ = 0.76). However, these results should be interpreted very cautiously for two reasons. First, both the 3-chamber and neuromast viability experiments were conducted by a single teacher (Teacher 5 and Teacher 6, respectively; see Table 3 and Online Resource 3); thus, Rex experiment and teacher are completely confounded for these two experiments. Second, Teacher 5, whose students had significantly lower SI than students taught by other teachers for the novel tank task, was the only teacher who used the 3-chamber experiment. As we note in the discussion, this teacher was also one of the first teachers to implement the Rex experiments in the study, and students complained about the large amount of data to collect. We return to this point further in the discussion.

Taken together, we conclude that there is very little variability in SI across classes (aside from one teacher's class). Additionally, the variability we did observe could not be accounted for by variations in

[3] Note, in the analyses above, the data reported from Teacher 5's students came from their second experiment using the novel tank. These data were already excluded from the original multi-level models. However, Teacher 5 also taught two classes using the 3-chamber tank experiments. It was the removal of these two classes that resulted in the reduced intra-class correlation (ICC) coefficient.

implementation, class level (e.g., regular, honors, AP), or the subject area of the course. Moreover, we found very little evidence suggesting that the different modules differentially impacted students' feelings of SI. Therefore, despite some variation in students and implementation, we conclude that Rex is generally supportive of SI.

Teacher Feedback on Rex Implementation

Overall, feedback from the teachers piloting Rex in their classrooms was positive. Teachers noted the value of the intellectual rigor of the content and the opportunity for students to engage with the collection and analysis of real data. Teachers rated each class's ability to engage with the academic content of Rex on a scale of 1 (Poor) to 5 (Excellent). Across the 13[4] classes using Rex, teachers rated students' ability to engage with the content of Rex as good ($M = 3.10$, $SD = 0.99$). Thus, Rex biological content was fairly challenging but manageable for most students.

Teachers also remarked that support from the authors during the implementation of Rex was helpful: "The little insights for website use and how to do things smoother were greatly appreciated." While most educators felt prepared implementing Rex even for the first time, others felt that tackling the novel academic content as well as technology troubleshooting (e.g., videos not loading due to internet instability) would have been challenging without outside support.

Discussion

Overall implementation of Rex was smooth, with some periodic internet connectivity issues. Student qualitative positive comments aligned with several of our goals in designing Rex, and negative comments led to some early adjustments in implementation of the experiments. Last, our preliminary findings concerning students' SI after completing a Rex experiment revealed that Rex held their interest regardless of the type of class, teacher, and choice of experiment.

[4] Note, these analyses include ratings from both the first and second experiment completed by students in Class 2 for Teacher 5.

Technology Issues

The technical challenges that we experienced were mostly attributable to two factors: internet security firewall issues and internet connectivity issues. Internet security in a school environment can be complex; firewall policies and implementations can be fluid, and some amount of trouble-shooting might be required prior to classroom implementation of an online experiment. As we discovered in our pilot classrooms, simply whitelisting the online videos with the school's IT personnel is not always sufficient; in our case users had to also log into their YouTube account. More broadly, we recommend that creators of any online experiment that uses videos and that will be implemented in a school environment should coordinate closely with the school's IT staff. To avoid implementation failure, the experiment should be tested well in advance, inside of the school firewall, using school computers, and logging in with a student account.

Our second major technical issue was related to internet connectivity. Any online virtual experiment will be vulnerable to internet connectivity issues, and thus a back-up plan is necessary. In our case, we included the actual dataset from each experiment in the teacher resources section of the website. Teachers can use the dataset to carry out data analysis and graphing in the classroom should the internet not be available to collect the data. However, the students do not get to participate in the most novel and perhaps most interesting part of the experiment, the data collection.

Ultimately, an inescapable vulnerability of online virtual experiments is the need for a reliable, fast internet connection. Alternative forms of delivery for virtual experiments include installable software or apps. However, downloadable delivery requires additional set-up time that teachers may not have, must account for very specific software system requirements for the hardware, and does not update automatically when changes are made to the virtual experiment platform. Online platforms, in contrast, provide instant access with no install necessary, and the user is always presented with the most recent version of the experiment, including any updates or edits.

Classroom Observations

Based on our observations in the classroom, it was clear that, in addition to the technical issues, teacher preparation and engagement during implementation was an important part of a successful Rex experience. As observers, we noted that Rex tended to run smoothly when the teacher had 1) set up groups who could work together, 2) discussed the background for the experiment, and 3) given practice dilution equations prior to implementing Rex in the classroom.

Our classroom observations further suggested that some students may not have the necessary reading and mathematical skills for our experiments to be completed in the recommended two 90-minute class periods. As we noted earlier, we made modifications for one class based on teacher feedback, creating an abridged version of a Rex experiment that students completed in one hour. Although the abridged format did not reduce SI, we feel this abridged version may not be sufficient for teaching students to fully understand the process of scientific inquiry, data collection, and analysis. Teachers who have lower performing students in their classrooms might benefit from having a teaching assistant help prepare for the Rex unit before implementing it in class. For example, a teaching assistant could give the students practice worksheets to carry out simple dilution calculations and discuss the background out loud before asking the students to read it.

Student Feedback about Rex

Student feedback at the end of each experiment revealed positive comments that align with our goals for the platform. Students liked the relevance of the experiments to everyday life, which maps to our goal of increasing interest in science by focusing on topics relevant to high school students. We also sought to immerse students actively in an actual scientific investigation; student comments regarding enjoying being involved with the experimental process and getting to collect real data suggest that this approach is a good “hook” for teaching the scientific method. The technical computing aspects of the experiment were popular among the students. Prior to Rex, some students had never worked with spreadsheets nor created graphs on a computer, and some students commented on enjoying learning and using these skills. Although learning such technical skills was not a primary goal of Rex, it is an added benefit that may also help improve computer literacy.

Among the negative comments, some students commented that they did not like that the experiment was virtual, and that they thought Rex was boring. Some students thought that they were going to get to do the actual experiment, and work with (for example) live zebrafish, and were then disappointed when they realized the experiment was limited to videos of the fish. Better introduction by certain teachers about the exercise may have prevented disappointed expectations.

Student Situational Interest

While we found that there was variability in SI by class in the overall analysis, it appears that all of the class-level variability we observed was a function of students from one teacher's classes (Teacher 5). There may be several factors that accounted for this variability. First, Teacher 5 was the only teacher who used the Three Chamber experiment. It could be there is something about this experiment that is too tedious or repetitive, which might lower SI. Indeed, our observations revealed that students appeared bored as they had to record a lot of data for 40 fish—in fact, we overheard complaints about it. Thus, for subsequent classes (using any experiment), we decided to "pre-fill" data for about one third of the subject animals to reduce the amount of data collection by the high school students. Second, Teacher 5 also used the Novel Tank experiment in this same class, and the SI scores were still lower than those observed in the majority of other classes for both the Three Chamber and the Novel Tank experiments. One possible explanation for the lower interest in the class that performed the Novel Tank experiment is that there were state-wide internet shortages on that day when the students were using Rex.

It appears that the degree of SI is similar regardless of some variation in how Rex is implemented. In fact, SI was similar across class levels (e.g., standard, honors, AP). The similar SI scores observed in biology classes of different levels is surprising given our observations that students in standard level courses struggled with some of the Rex material even if they did not have the abridged version. A possible explanation for this discrepancy is that we made appropriate adjustments prior to the implementation of Rex for students in lower level courses, and provided additional help with data collection, possibly preserving any potential loss of SI. Thus, we conclude that teachers can use Rex at a variety of academic performance levels, if tailored appropriately.

Second, based on our initial results, we conclude that teachers may use whatever Rex experiment fits with their curriculum and still garner reasonable student interest; the only variation in SI that we found as a function of Rex experiment is likely attributable to teacher variation rather than true differences based on the experiment. Nonetheless, this question of variability as a function of Rex experiment type needs to be explored with more teachers conducting each experiment and testing of all the Rex experiments available (three of the Rex experiments were not implemented by any teachers). Future research should also investigate whether engaging in more than one Rex experiment generates an even higher level of SI. Taken together, we find these preliminary results encouraging--teachers can implement Rex in a variety of ways to support a moderate degree of SI.

Future Directions

The Rex platform incorporates elements that have been shown to be effective with regards to student achievement. These elements include 1) a blended online/classroom learning environment (vs only online or only in the classroom), 2) small-group learning, 3) project-based learning, and 4) authentic research activities (Yaron et al. 2010; de Jong et al. 2013; Schneider and Preckel 2017). Although beyond the scope of the current study, we plan to determine the impact of Rex on student performance by assessing changes in their critical thinking skills; such data will help address the current paucity of virtual lab effectiveness studies at the K-12 level (Brinson 2017). By engaging students in learning about scientific concepts as well as the *process* of doing science by engaging in scientific practices, authentic virtual experiments have also been proposed as a means to improve general attitudes about science and scientists (Chen 2010; Yaron et al. 2010). In this regard, our future efforts will also assess whether Rex affects general attitudes toward science (i.e. *individual interest*).

Conclusion: Virtual Lab Experiments and the Classroom

Non-traditional laboratories, and specifically virtual laboratory experiments such as Rex, have been shown to be equally if not more effective than traditional physical laboratories when measuring student learning outcomes (Rutten et al. 2012; de Jong et al. 2013; Brinson 2015). However, many virtual laboratories use a hypo-deductive model of inquiry that presents an over-simplistic model of the scientific process (Chen 2010). It is important to teach students not only scientific concepts and skills, but also the process of scientific inquiry, a process that is more accurately represented by the holistic model than the hypo-deductive model (Chen 2010) and is aligned with recent reform efforts' emphasis on engagement in scientific and engineering practices (NRC 2012, 2013). Rex supports teaching this holistic model of inquiry by involving students in an authentic scientific investigation that encourages students to incorporate background information, consider multiple alternative explanations for their results, and think about potential sources of error and possible future experiments.

Table 1. The Rex Experiments

Type of Experiment	Experiment Title	Abbreviated Title	Reference
Behavior	Stress and Anxiety: The Novel Tank Test & Zebrafish Exposed to Caffeine	Novel Tank	Egan et al. 2009 Cachat et al. 2010 Wong et al. 2010
Behavior	Learning and Memory: The Three-Chamber Tank Test & Zebrafish Exposed to Ethanol	3-Chamber Tank	Gerlai et al. 2000 Echevarria et al. 2011
Behavior	Spatial Learning: The Morris Water Maze & Adolescent Rats Exposed to THC	Water Maze	Cha et al. 2006 Vorhees and Williams 2006
Physiology	Development of Sense Organ Function: The Startle Response in Zebrafish Larvae Exposed to Ethanol	Startle Response	Kimmel et al. 1974 Carvan et al. 2004 Buck et al. 2012
Cellular	Development of Sense Organs: Viability of Neuromasts in Zebrafish Larvae Exposed to Ethanol	Neuromast Viability	Carvan et al. 2004 Ton and Parng 2005 Buck et al. 2012
Molecular	Gene Expression: In Situ Hybridization of mRNA in Rats Exposed to Cigarette Smoke	Gene Expression: Cigarette Smoke	Bahk et al. 2002
Molecular	Gene Expression: In Situ Hybridization of mRNA in Adolescent Rats Exposed to THC	Gene Expression: THC	Ellgren et al. 2007

Table 2. Student Demographics

	Demographic	%
Gender	Male	31.5
	Female	63.6
	Other	4.9
Race/Ethnicity	Black or African American	30.3
	Hispanic or Latino/a	28.1
	European American or White (not Hispanic)	24.2
	Asian or Asian American	8.4
	Multiracial	8.4
	American Indian or Alaska Native	0.6
	Native Hawaiian or other Pacific Islander	0.0
Grade level	Freshman	1.2
	Sophomore	38.7
	Junior	32.8
	Senior	27.3

Table 3. Experiment implementation details

Class ID	Teacher[a] ID	School ID	Course	Level	Number Sections	Experiment	Overall Observer Score
1	6	2	Biology	Honors	1	Neuromast Viability	4.6
*2	5	1	Forensic Science	Honors	1	3-Chamber Tank	4.2
3	5	1	Biology	Honors	1	3-Chamber Tank	3.8
4	4	4	Anatomy/ Physiology	Honors	1	Novel Tank	4.5
5	2	1	Biology	Honors	1	Startle Response	5.0
6	2	1	Biology	AP	1	Startle Response	5.0
7 & 8[b]	8	3	Biology	Honors/ Standard	1	Startle Response	5.0
9	7	4	Biology	AP	1	Novel Tank	2.3
10	1	3	Biology	Honors	1	Startle Response	3.9
11	1	3	Anatomy/ Physiology	Honors	1	Startle Response	3.8
12	7	4	Biology	Standard	1	Novel Tank[c]	2.2
13	1	3	Biology	Standard	1	Startle Response	3.8
*14	5	1	Forensic Science	Honors	1	Novel Tank	3.0

*Class ID 2 and 14 are from the same classroom but designate two different Rex experiments performed at different times

[a]Teacher ID 3 was excluded from the study for technical reasons

[b]This class contained both honors and standard students (a separate class ID code was given for statistical coding)

[c]This class of lower performing students had a 1 hour version of Rex

Ethical approval: All procedures performed in studies involving human participants were in accordance with the ethical standards of the institutional and/or national research committee and with the 1964 Helsinki declaration and its later amendments or comparable ethical standards.

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Figure Legends

Fig. 1 Infrastructure of the Rex web platform. The Rex website is hosted on the Heroku server. Each of the components that host registration/application data, experimental data, videos, and Notebook spreadsheets interact with the host server

Fig. 2 Typical main panel in a Rex experiment, featuring two of the Rex scientists, all of whom were doctoral students in basic sciences. Red boxes restate questions posed in the videos for students to answer; clicking the box opens the Rex Notebook (shown in Fig. 3) to the appropriate item. Users can navigate using the Next/Previous buttons

Fig. 3 Open navigation menu on left and Notebook on right. Both the navigation menu and Notebook are collapsible, revealing the central content behind

Fig. 4 Dose choice options. Students select the doses for the experiment. Correct choices turn red, while incorrect answers trigger a pop-up explanation for the error. Students then write their choices in their Rex Notebook

Fig. 6 Variability in Situational Interest (SI) by Class. Each gray dot is an individual student SI score. SI scores on the Y-axis ranged on a Likert Scale from 1 (strongly disagree) to 5 (strongly agree). Dashed horizontal line represents the grand (overall) mean. Each red star represents the group mean responses of the students in each class estimated from the mixed-effects model (taking account of the mean and variability of the responses in the class relative to the overall mean and variability). The black circle represents the raw mean of the responses of the students in each class. Only students' responses to the first experiment are depicted; thus, there are no responses included for class 14, which was the second experiment for class 2. Classes 7 and 8 are combined as these represent a single physical classroom

Fig1

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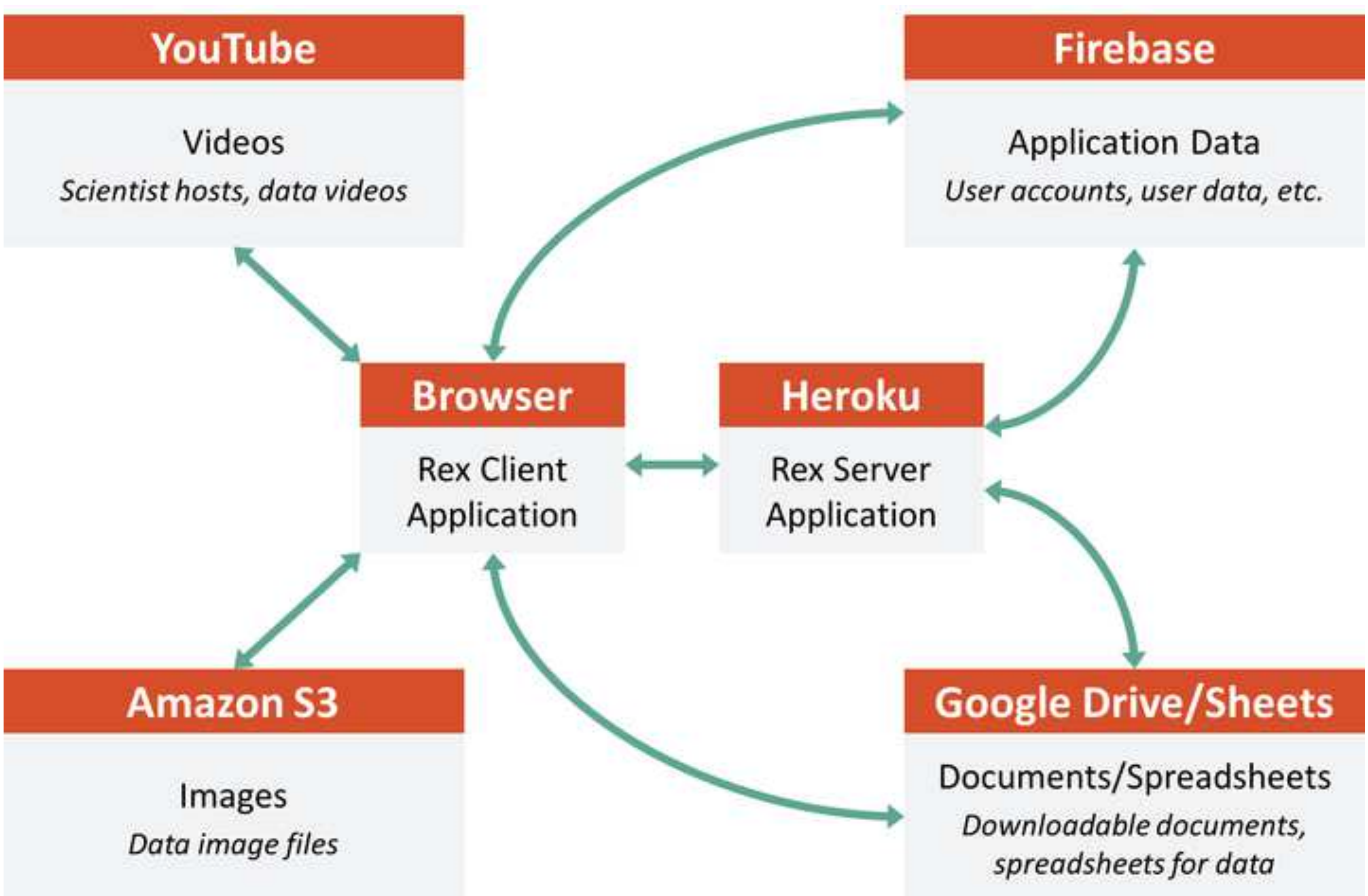

Fig2

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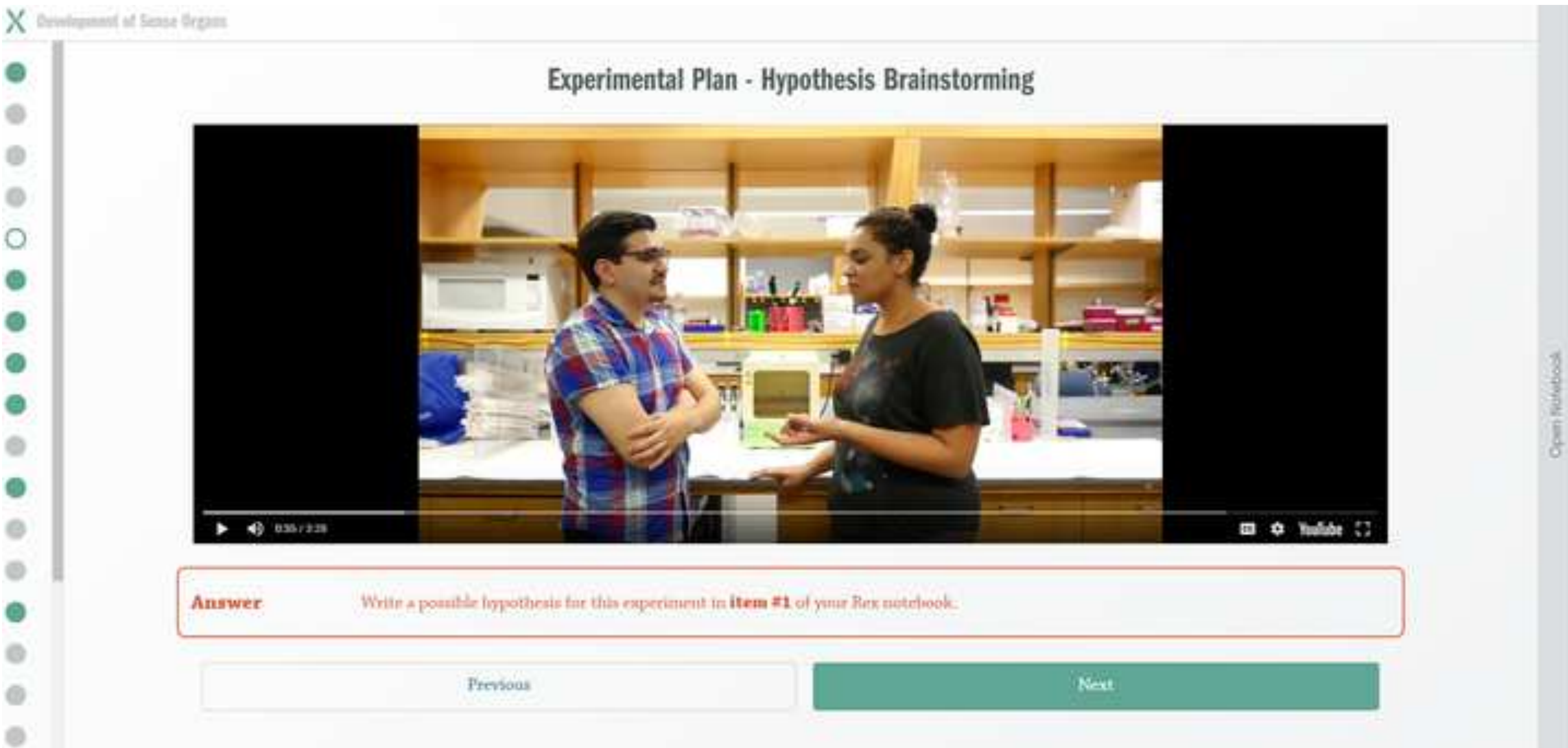

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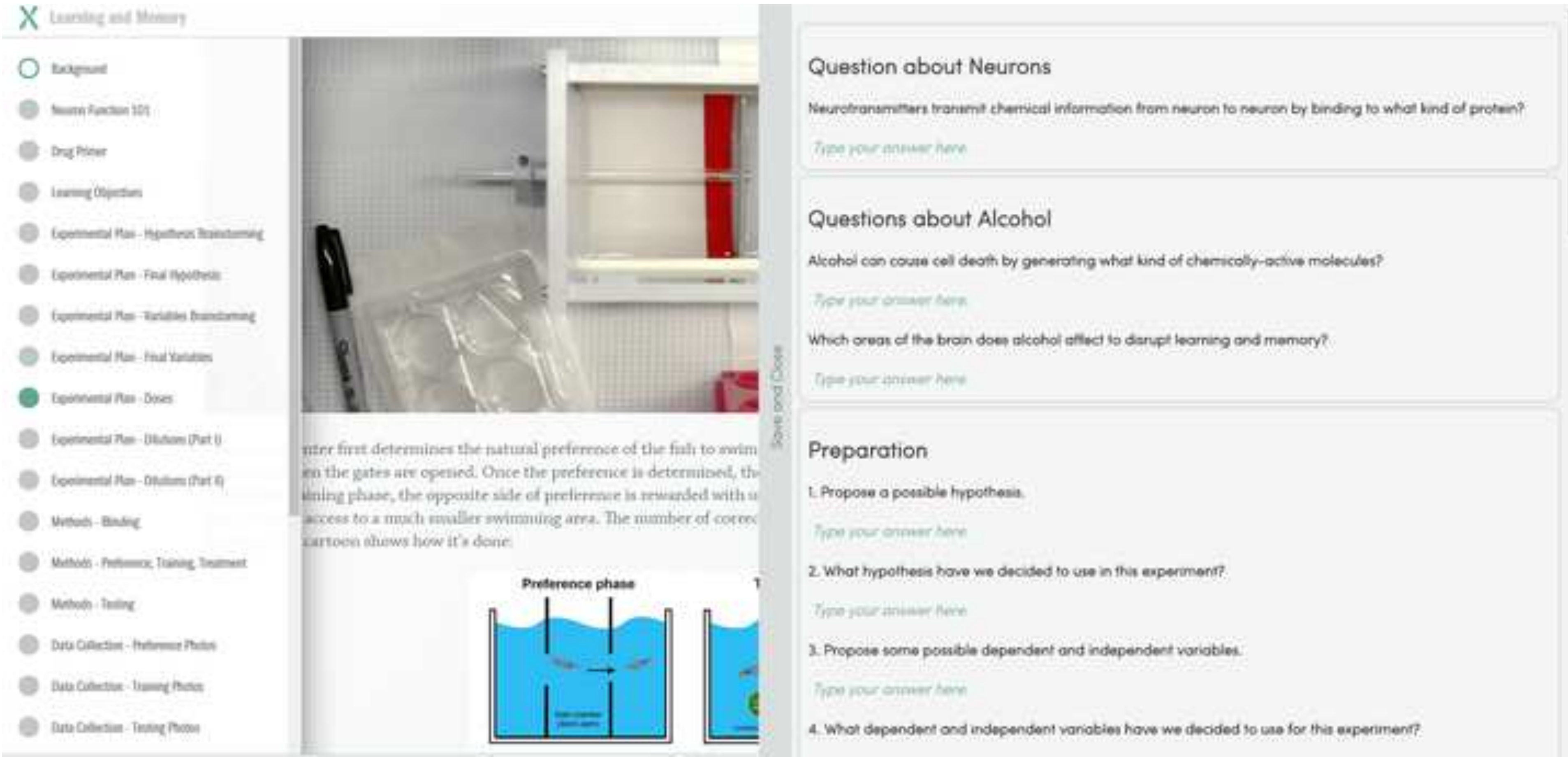

Fig4

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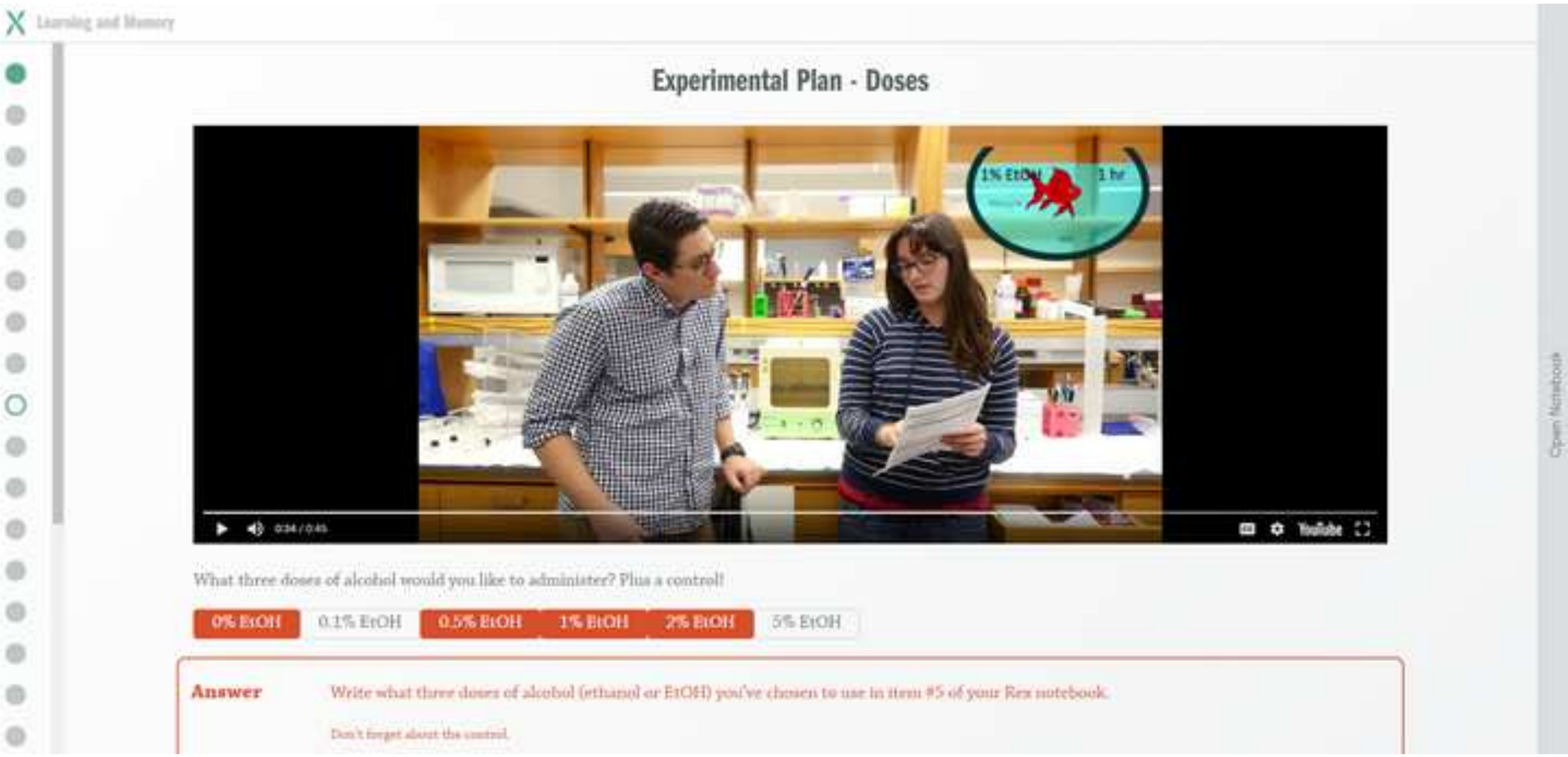

Fig5

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