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Development of an Online Experiment Platform for High School Biology

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Abstract
We developed a novel online platform, Rex (**R**eal **ex**periments), that immerses students in a scientific investigative process. Rex 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. Seven neuroscience experiments use zebrafish and rats as model systems to study the effects of drugs such as tetrahydrocannabinol (THC), caffeine, alcohol, and cigarette smoke, which are of interest to high school students. We carried out a small field test of Rex in a variety of high school biology classrooms (e.g., standard, honors, AP, anatomy/physiology) to obtain student and teacher feedback about the implementation and usability of the program. We also assessed student situational interest (SI) to determine whether the Rex experiment captured students' attention, and whether it was an enjoyable and meaningful experience. Overall, students reported a moderate level of SI after participating in the Rex experiments. Situational interest did not differ across teachers, class section, class level, or the type of experiment. In addition, we present details of the technical issues encountered in the classroom, and we provide guidance to readers who may want to use the resource in their classrooms.

Keywords Online lab experiments · High school biology · Virtual experiments · Neuroscience · Drugs · Situational interest

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 USA have several challenges for teachers to overcome. Many high school laboratory experiments are cookbook-style and uninspired (McComas 2005; Modell and Michael 1993), scientific practices and the scientific content being taught are not always integrated together effectively despite recent reform efforts (National Research Council 2006, 2012), and laboratory experiments are not always interesting to students nor relevant to their daily lives. Furthermore, many high school lab experiments are not conducted as authentic research experiences, which the Next Generation of Science Standards (NGSS Lead States 2013) states is important in helping students engage in the practice of science and understand the nature of science. These issues are exacerbated by contextual factors present in many high schools. For example, the time it takes to plan, set up, and manage high-caliber experiments may compete with other course requirements. Further, teachers may have limited experience with cutting-edge research techniques and schools may not have the resources to purchase the various scientific equipment necessary to carry out many experiments (Gomes and Bogosyan 2009). Finally, in the case of biology, some jurisdictions restrict the use of vertebrate animals for experimentation in K-12 schools (NABT.org 2008).

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Some ways to address many of these limitations are the use of "dry" bench (e.g., using computer databases) laboratory experiments (Munn et al. 2017) or non-traditional laboratory experiments (Brinson 2015; Ma and Nickerson, 2006). Non-traditional lab experiments 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 (Brinson 2015; Childers and Jones 2015; Guerra-Varela et al. 2016; Heradio et al. 2016; Ma and Nickerson 2006). Both dry bench and non-traditional laboratories not only reduce costs, they provide the additional benefits of availability, accessibility, and safety (Gravier et al. 2008; Heradio et al. 2016). Munn and colleagues (2017) have shown that conducting an experiment on the same topic with wet (genotyping DNA) or dry (database research) techniques provides students with similar views on the nature of science in the real world. Furthermore, a 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). At the college level, Rowe et al. (2018) have found that students using virtual/computer simulation laboratories in chemistry perform as well or better than students enrolled in traditional chemistry lab courses.

A variety of resources are available online to support students' learning in science. Such resources can range in interactivity from simple animations, to click-and-learn interactive demonstrations, to educational video games, and to virtual laboratory experiments. Participation in online labs may include performing experiments, collecting data, and answering questions (Guerra-Varela et al. 2016; Liu et al. 2001; Rowe et al. 2018). Examples along the entire range of this spectrum can be found on the Howard Hughes Medical Institute's BioInteractive Web site (http://www.hhmi.org/biointeractive/). Many programs have been developed to incorporate technological supports for learning in diverse scientific fields including nanotechnology (Tarng et al. 2017), ecology and biodiversity (Hardisty et al. 2016), and astronomy (http://www.golabz.eu/lab/galaxy-crash). Additionally, research in blended learning has shown that incorporation of online activities for feedback, documentation, and ease of access to information meaningfully enhance traditional instruction without sacrificing the benefits of face-to-face communication (Hill, Chidambaram, and Summers 2017).

However, many virtual laboratories use a hypo-deductive model of inquiry that presents an oversimplistic model of the scientific process (Chen 2010). Often, virtual labs present an ideal world using simplified conditions and perfect data that conform neatly to the hypotheses. Virtual labs 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 platform 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, is a virtual Web-based biological science experiment platform—it is hosted by real scientists and uses actual lab experiments that generate real data for students to collect, analyze, and interpret. Rex was designed 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). Rex is aligned with recent reform efforts' emphasis on engagement in scientific and engineering practices (NRC 2012; NGSS Lead States 2013).

The Rex platform was designed to address several of the 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 foster interest in science. Therefore, we focus on topics in pharmacology and neuroscience, subjects 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 (Kwiek et al. 2007; Schwartz-Bloom et al. 2011; chwartz-Bloom and Halpin 2003). As high school students graduate to become college students, an early experience in conducting pharmacology experiments increases student majors in science and in pharmacology (Godin et al. 2015). Therefore, 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). Situational interest 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 it is also related to academic engagement and achievement (Schiefele 2009). In this study, we measured situational rather than individual interest, as SI is the psychological construct most likely to be shaped by participation in one of the Rex modules. For example, students would likely need to engage in multiple modules for the Rex experience to have an impact on their more enduring individual interest. 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 describe our preliminary implementation of Rex in eight high school biology classrooms in North Carolina. We discuss teacher training, classroom visits for implementation observation and technical support, and the various technical challenges encountered, and we summarize our post-Rex feedback from teachers and students. In addition, we share our assessment of students' SI to determine whether the Rex experiment captured students' attention, and whether it was an enjoyable and meaningful experience. Notably, the goal of this report is to share with readers the process of developing our Web-based virtual experiment so that others interested in this type of work can learn from our experiences. Our findings presented here regarding both teachers' and students' reactions to the Rex environment provide results of the first iteration of our design-based research on the platform. Design-based research focuses not only the process of iteratively developing and testing a tool or intervention, but understanding it in an authentic context (The Design-Based Research Collective 2003). In the context of technology-enhanced learning environments (TELE), design-based research can also generate practical knowledge that will help the TELE design community (Wang and Hannafin 2005). Thus, our aim is to understand how the platform can be further developed to support students' participation in authentic science labs, and also to understand students' experiences of and reactions to those labs. An evaluation of the efficacy of the Rex platform on learning is beyond the scope of this study and is a future goal in a substantially larger intervention.

Program Design

Overview of the Program Components

The Rex program included several components: (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, and (5) development of a teacher tutorial. Each of these features is presented below.

The Rex Program Elements

Program Architecture Rex is a multicomponent 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 Web browser (ideally Google Chrome). 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), (3) a Web storage service for the data image files from experiments (Amazon S3/Cloudfront), and 4) a video-sharing Web site that hosts the scientist videos (YouTube). 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 Web site is designed and supported for the Chrome browser, although it may run in other browsers as well.

General Web Site Design

The Rex platform presents seven individual neuroscience experiments (Table 1). Once users choose an experiment, they are guided through the experiment by a navigation menu and by the scientists via YouTube videos. Each Rex experiment is organized in the same way a real experiment is conducted, starting with background reading about the topic, 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 visualization. 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 contains (1) short text sections (e.g., background; Fig. 2), (2) videos of the scientists (Fig. 3), (3) questions to answer (Fig. 3), and (4) data generated from the experiments (Fig. 4). The navigation menu on the left of the panel (Fig. 5) can be used to jump to any point in the experiment. The Notebook, which opens on the right of the panel (Fig. 5), 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. In addition to the navigation menu and video controls, we provide pop-up definitions for keywords and optional links to more detailed background information and tutorials (Fig. 6).

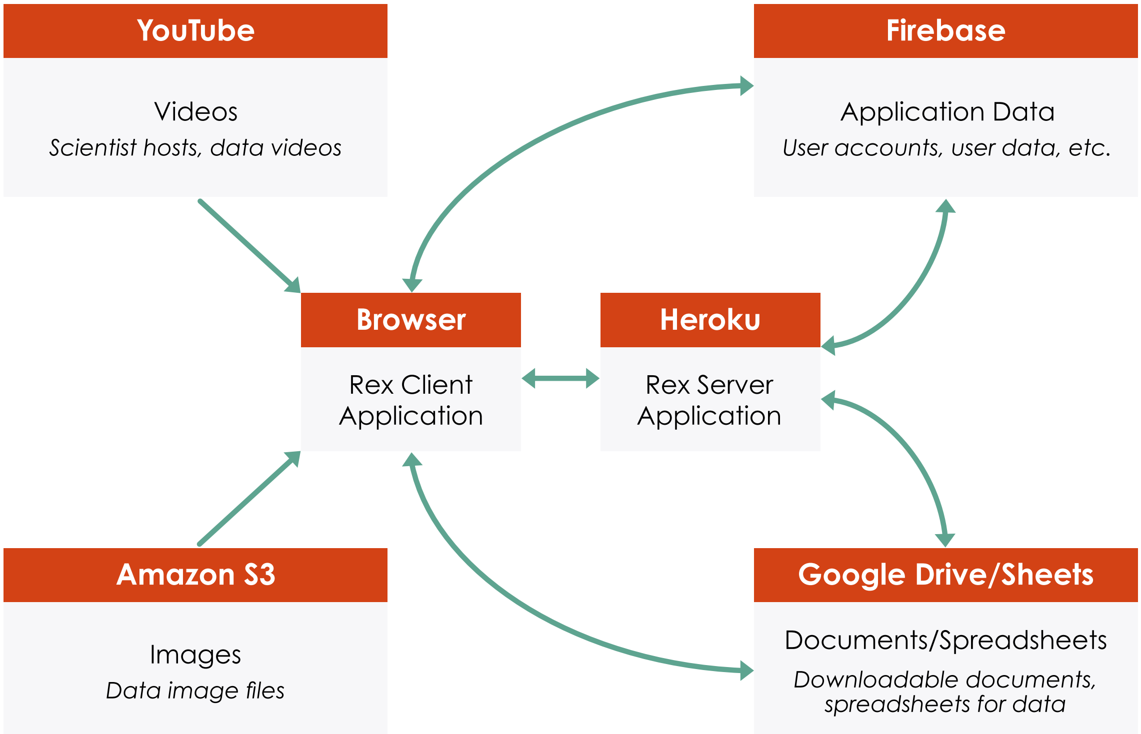

Fig. 1 Infrastructure of the Rex Web platform. Each of the components that host registration/application data, experimental data, videos, and Notebook spreadsheets interact with the host server (Heroku). The double arrows show information that flows to and from one component to another, e.g., a student's browser both reads and writes data from/to Firebase or Google Drive. The single arrow shows information that flows in one direction, e.g., a student's browser receives video or image content, but does not write any new data to YouTube or S3. A subset of information from Firebase and Google Drive is communicated to/from the Browser through the application on Heroku

The Rex Experiments The seven Rex experiments are based on previously published neuroscience studies. The experiments are grouped into four approaches: (1) behavior, (2) physiology, (3) cellular, and (4) molecular (Table 1). Some experiments had a simple design and implementation, and others had a more technology-driven and sophisticated implementation (e.g., the molecular biology experiments). The experimental organisms are zebrafish (*Danio rerio*) and rats (*Rattus norvegicus*), which are well-established, simple models for the effects of drugs on humans (Guerra-Varela et al. 2016; Iannaccone and Jacob 2009). An overview and some considerations of each experiment can be found on page 17 of the Teacher Tutorial (Online Resource 1).

Members of the principal investigator's lab (not the hired graduate student actors) performed the experiments to generate real data that would eventually be stored on the cloud servers for student access. However, the raw data from the spatial learning and gene expression experiments were obtained from the respective published studies. 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.

A written protocol of each experiment (with the data filled into the tables and sample graphs) is included in the Teacher Resources section in Rex. It contains additional information for the teacher such as mapping of the science content and process to the Next Generation Science Standards (NGSS Lead States 2013) and the Common Core Standards for Mathematics (National Governors Association Center for Best Practices, Council of Chief State School Officers, 2010). The protocol allows the teacher to actually run the experiment in a biology laboratory should (s)he have the resources. A copy of the protocol for the Startle Response experiment is included on page 6 in the Online Resource 1.

The Rex Scientists and Filming A key feature of Rex is the series of short video clips of real scientists (10 graduate students) performing the experiments and "interacting with" the high school students (for example, Fig. 7 and on page 5 in Online Resource 1). We chose the doctoral graduate students in basic sciences from our university from a larger applicant pool to serve as actors performing the experiments for the video segments embedded in Rex. Of the ten scientists, six were women and four were underrepresented minorities (one African American, three Hispanic/Latino). Their departmental affiliations consisted of pharmacology, neurobiology,

Table 1 The Rex experiments

Type of experiment	Experiment title (abbreviated title)	Experiment description	Reference
Behavior	Stress and Anxiety: The Novel Tank Test & Zebrafish Exposed to Caffeine (Novel Tank)	Test the ability of caffeine to induce stress/anxiety in the adult zebrafish when swimming in a novel environment, e.g., measure time spent in "safe" area (time spent in top half of the 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)	Test the ability of ethanol to disrupt learning and memory in the adult zebrafish. Fish must remember to swim to its preferred side of the tank. Measure the number of errors/time.	Gerlai et al., 2000; Echevarria et al., 2011
Behavior	Spatial Learning: The Morris Water Maze & Adolescent Rats Exposed to THC (Water Maze)	Test the ability of THC to disrupt learning and memory in the adolescent rat. The rat must learn and remember where to find the submerged platform in a swim tank. Measure the distance the rat travels to find the platform over 3 weeks.	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)	Test the ability of ethanol to disrupt the development of the startle response in zebrafish larvae. Measure the reflex movement in response to a vibrational stimulus (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)	Test the ability of ethanol to damage the sensory cells in the zebrafish larvae (responsible for the startle response). Visualize neuromasts (in microscope images) stained with a vital fluorescent dye. Assign fluorescence intensity scores of each neuromast to reflect cell damage.	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)	Test the ability of cigarette smoke to change expression of genes in the rat brain associated with addiction. Measure mRNA expression in brain photomicro-graphs (2-week exposure to cigarette smoke) using an image analysis program to measure grain density of the radioactive cDNA probe bound to mRNA.	Bahk et al., 2002
Molecular	Gene Expression: In Situ Hybridization of mRNA in Adolescent Rats Exposed to THC (Gene Expression: THC)	Test the ability of THC to change expression of genes in the adolescent rat brain associated with addiction. Measure mRNA expression in brain photomicrographs using an image analysis program to measure grain density of the radioactive cDNA probe bound to mRNA.	Ellgren et al., 2007

biochemistry, cell biology, and biology. The graduate students were chosen primarily based on previous experience with the different experimental techniques used in Rex and their interest in gaining experience in science education at the precollege level.

Pairs of scientists led an experiment on video, 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, which included demonstrations of the actual equipment used in the experiments. After filming, the video segments were uploaded to YouTube.

The video segments have many of the elements discussed by Brame (2016) that can maximize student learning, including providing active learning, fostering student engagement, and managing the cognitive load. For example, the videos were designed to provide students with an active role in the experiment, despite the lack of a physical hands-on component. To encourage interactivity, the videos end with the scientists posing a question to the students and telling the students to write their answer in their Rex Notebook. To reinforce the questions, we placed a red box underneath the video window (Fig. 3) 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. To foster engagement further, 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. 7) 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). Thus, allowing the students to choose their experimental parameters still allowed them some ownership of the experiment even though the experiment had already been performed by the scientists. The guiding and interactive questions and the features that give students control, may increase germane cognitive load, improve memory, and improve student

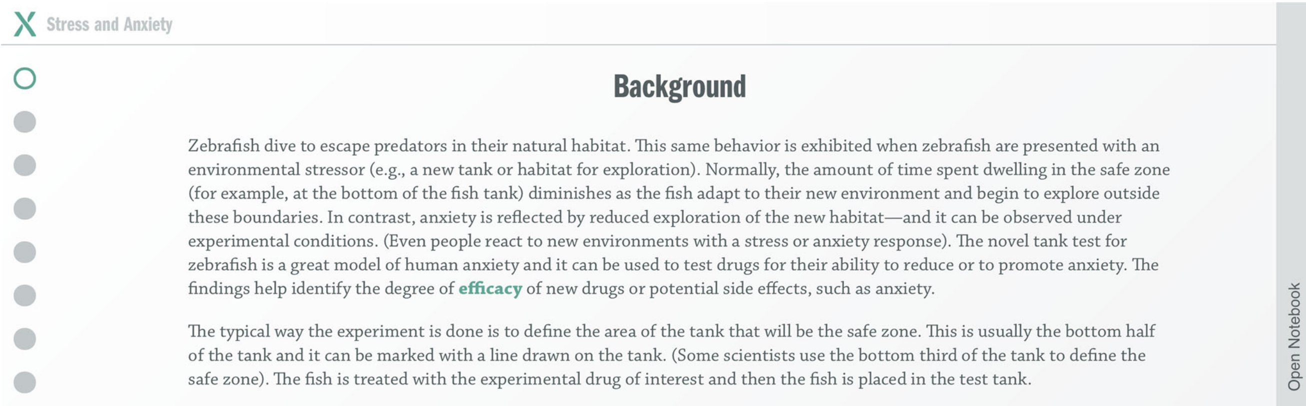

Fig. 2 Main panel in a Rex experiment contains text. Text such as "Background" resides in the main panel. Students read supporting information about the experiment. To see this feature in video format, click the link here: https://youtu.be/KrTKfXT2LmU

self-assessment (Brame 2016). Furthermore, by keeping the video segments short (~ 1–2 min), we may foster the percentage of videos watched, and reduce mind-wandering (Brame 2016). Both the videos and the platform elements are designed specifically to reduce cognitive load. The videos use segmenting to chunk information and help students perform specific tasks in order; segmenting videos can help manage students' connections (intrinsic load) and enhance their level of cognitive activity (germane load) (Brame 2016). For example, students are asked to first think about a hypothesis, then describe dependent/independent variables, and finally to help define the experimental parameters (dose, time, etc.). The scientists in the videos also lead the students through data collection, data analysis, and data visualization in a step-by-step manner. These features are found in the videos of each of the seven experiments. An example of scientists in a video is found in Fig. 7.

Students can replay any videos anytime in case they want to review the content. To accommodate a diverse group of learners and make the video content more accessible, a complete narrative script is included in the supporting Teacher Resources within the Rex Web site; students may also choose to use the closed captioning features on YouTube. An example of one of the video segments from the *Development of Sense Organ Function: The Startle Response* lab can be viewed on page 5 in the Online Resource 1.

The Rex Notebook The Rex Notebook (Fig. 5) is used in the same way a lab notebook is used by scientists. Every piece of information about the experimental design and data collection

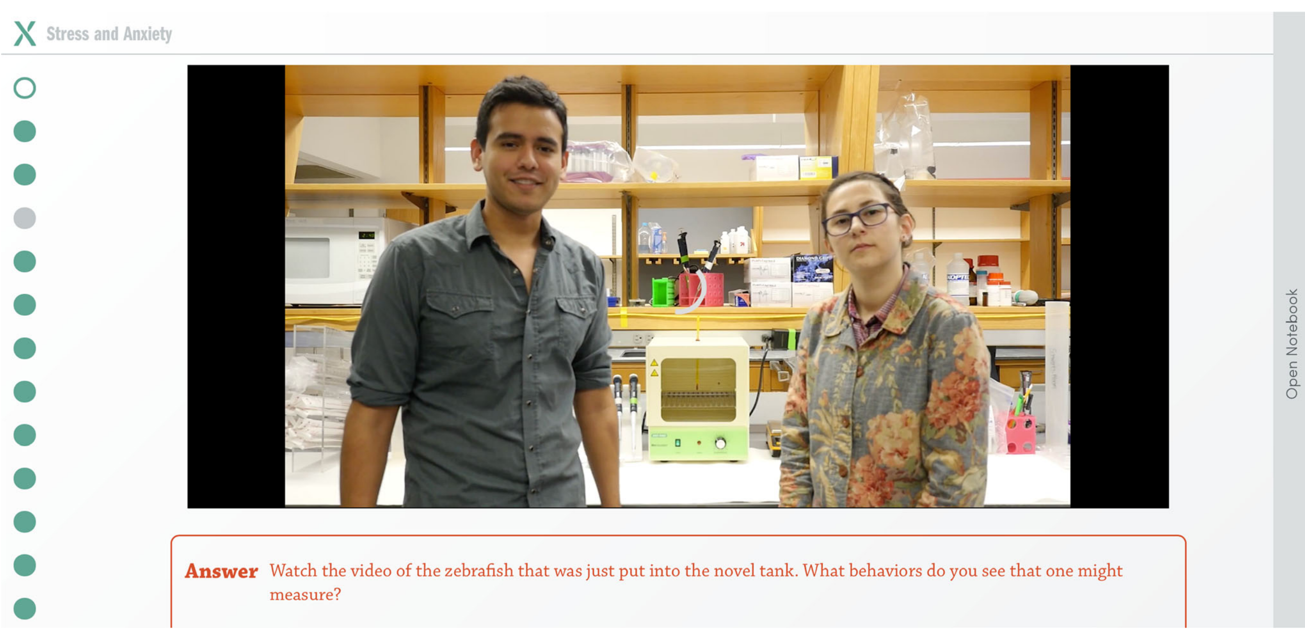

Fig. 3 Main panel in a Rex experiment contains videos. Videos reside in the main panel—this one features two of the Rex scientists—doctoral students. Red boxes beneath the videos restate questions posed in the videos for students to answer; clicking the box opens the Rex Notebook to the appropriate item. To see these features in video format, click the link here: https://youtu.be/KrTKfXT2LmU

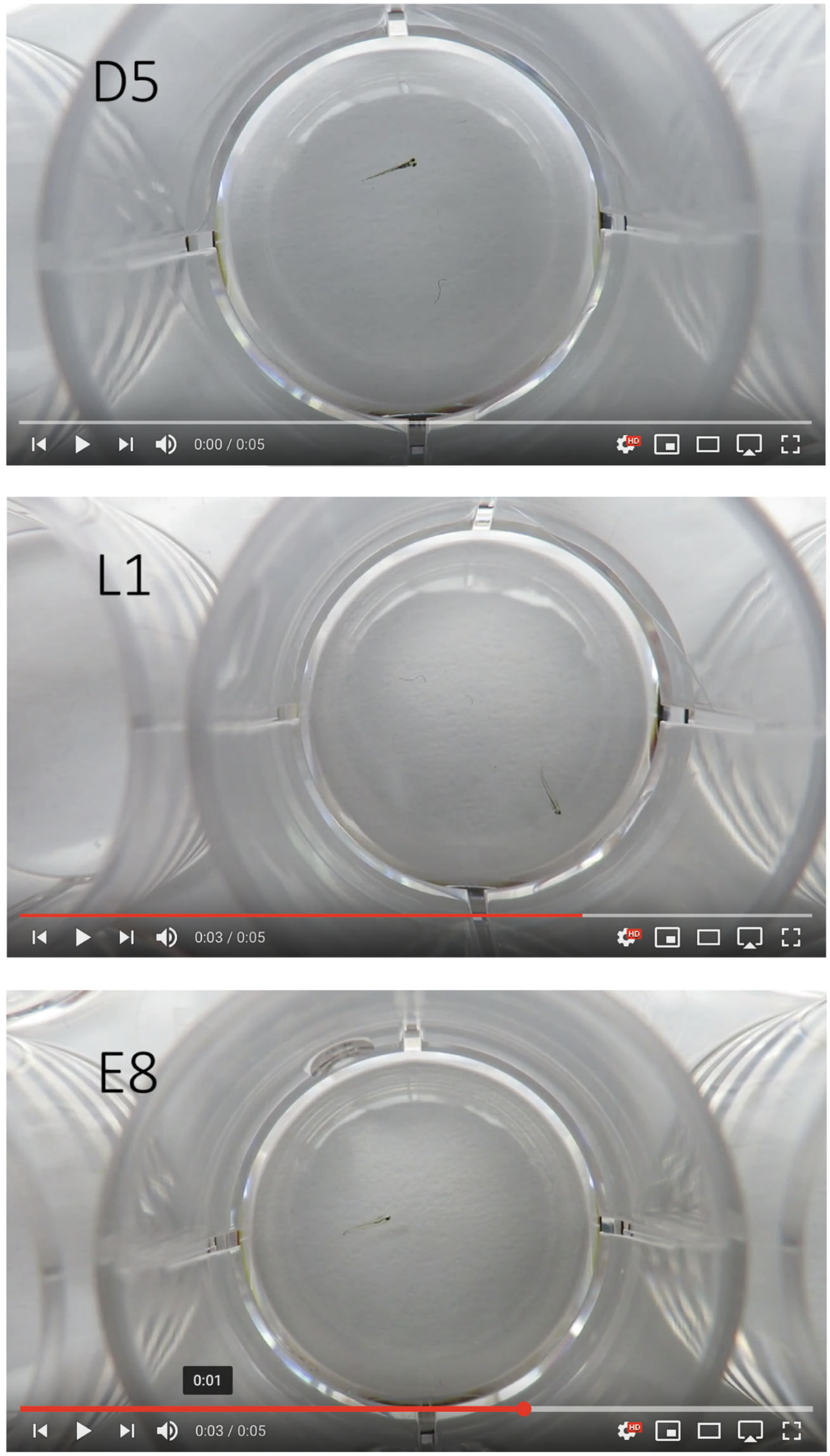

Fig. 4 Main panel in a Rex experiment contains data. Original data (either videos or images) generated in the experiments reside in the main panel. In this example, students collect their own data from the video recordings of zebrafish larvae subjected to the acoustic startle test. The student, blind to the treatment condition, provides a subjective score of 0 to 3, depending on how far the fish moves after the startle. To see the videos that the students see, click the links for each fish
Fish D5: https://youtu.be/amGASlLKxTM?list=PLqAAN1AH9H6f_HRfZDzOFJcQjyU2jJM_P
Fish L1: https://youtu.be/fsf2rUPbBXY?list=PLqAAN1AH9H6f_HRfZDzOFJcQjyU2jJM_P
Fish E8: https://youtu.be/4S6HQiyP81A?list=PLqAAN1AH9H6f_HRfZDzOFJcQjyU2jJM_P
After scoring the fish behavior and breaking the code, students learn that D5, L1, and E8 were treated with 0, 30, or 100 mM ethanol, respectively.

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. 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. In the ensuing video, the scientists thank the students for all their ideas, and then discuss what the best hypothesis would be for measuring a response. The scientists ask the students to rewrite a hypothesis in their own words that reflects the discussion by the scientists. 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

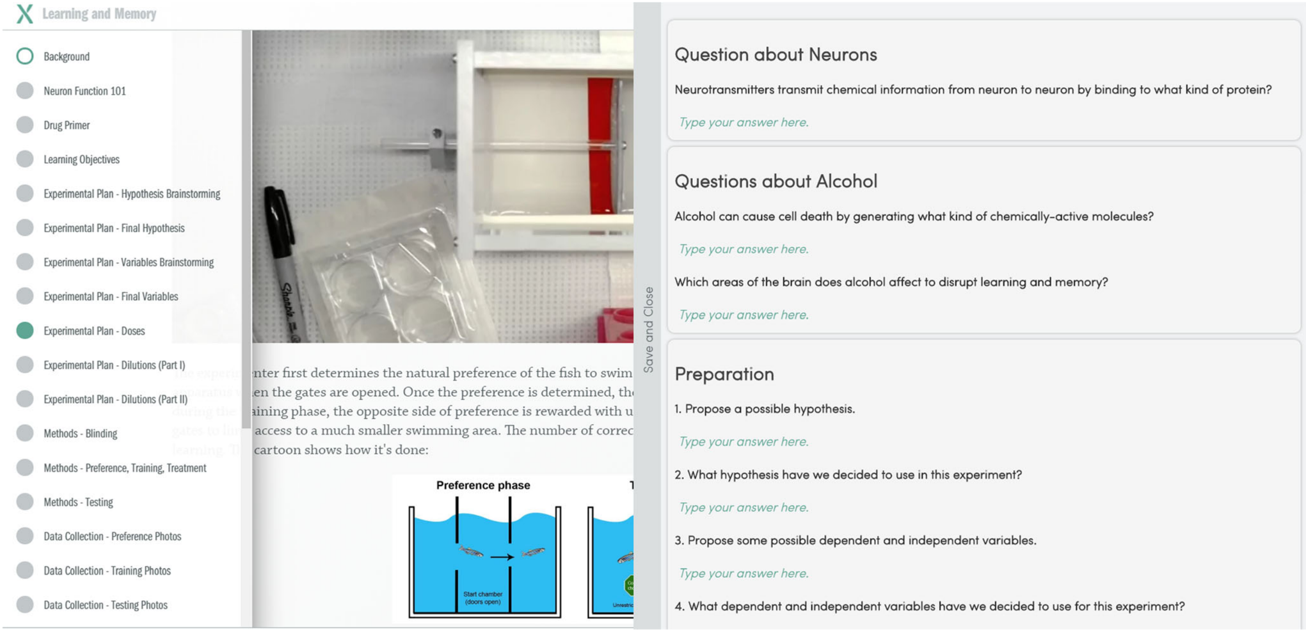

Fig. 5 The navigation menu on the left and the Notebook on right are both open. Both the navigation menu and Notebook are collapsible, revealing the central content behind them. To see these features in video format, click the link here: https://youtu.be/KrTKfXT2LmU

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. Once the spreadsheet is opened, it remains specific to that individual and it is then stored in a Google Drive that is owned by the authors associated with the program. Following the recording of their data into the spreadsheets, students are prompted by the scientists on video to use an online statistics calculator (found at http://astatsa.com/OneWay_Anova_with_TukeyHSD) to perform simple statistics with their data sets and then graph their data, either using the Google Sheet or manually on their own graph paper; teachers made the decision which format to use. Teachers have access to sample data spreadsheets and graphs in each experimental protocol document within the Teacher Resources section. Teachers have the option of skipping the part of the statistics section that includes the ANOVA and post hoc test, as these operations are outside the scope of the high school Common Core Standards for Mathematics (National Governors Association Center for Best Practices, Council of Chief State School Officers 2010).

Tutorials are provided within Rex to help students practice dilution calculations, perform data analysis and graphing and make the statistical analyses. After students perform their statistical analysis, they are prompted to answer several critical thinking questions about the experiment, which they type in the Rex Notebook. When finished, the student can then submit the Notebook to the teacher electronically and print out a pdf for themselves. 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 and whether the student has skipped items. If a submitted Notebook is incomplete, or needs revision, the teacher can release it back to the student to address the deficiencies. Once the Notebook is submitted, no further changes can be made unless the teacher has released it back to the student.

The 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 (Teacher Resources section). 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 and they can adjust or tailor different features, e.g., skip the statistical analyses, assign some sections as homework, and provide additional materials for class discussion.

Technical Requirements for Rex Access

Many schools have restrictions in their internet security firewalls and blacklist most URLs (Web addresses) that are not supported by the school system, including portions of YouTube.com. Thus, we provided the subject

Fig. 6 Supporting features in a Rex experiment. **a** In menu items that contain text, such as Neuron Function 101, students can click on words highlighted in green to view a definition pop-up box. **b** In menu items that contain text, such as the Statistics Analysis, links are provided for students to open tutorials for more information—in this example, students can link to the comprehensive Statistics Tutorial that is found in the general resources section

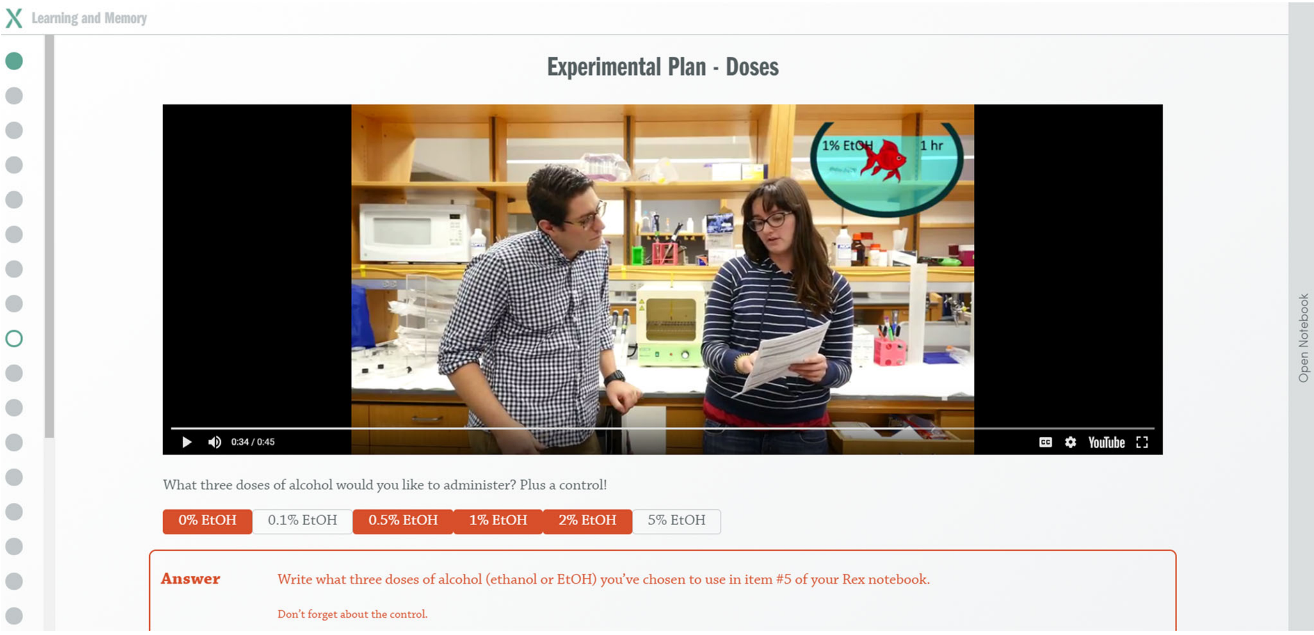

Fig. 7 Dose choice options. Students select the doses for the experiment. Correct choices turn red, while incorrect answers trigger a pop-up explanation for the error. Students then write their choices in their Rex Notebook. To see scientists talking with the students about choosing their doses, click the link here: https://youtu.be/KtCT1IR1WiY

school district's Information Technology (IT) department the URLs of all the Rex YouTube videos and other web resources to be allowed through the firewall (i.e., whitelisted). Second, 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. Access to Google Sheets and Google Drive did not require any whitelisting in the subject school district's system, as the school district uses Google features normally.

Methods

We carried out several assessments to provide formative information about the program design and its implementation in local high school biology classes. Both teachers and students participated in the formative assessments.

Participants

High School Teachers

Seven biology teachers from four high schools in a single school district in North Carolina participated in the project. The subject school district is under-resourced with an average of 58% high school students enrolled in free and 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 six years' high school teaching experience, ranging between two and 28 years. All teachers had Master's degrees. Two of the teachers (both female) participated in the preliminary testing and the remaining five participated in the initial rollout field test.

A week before 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; the teachers role-played their students and the authors role-played the teachers to model their role in guidance and support during the implementation in their classes. The teachers provided helpful feedback so that we could edit features and include additional resources for their classrooms prior to launching the field test. Upon release of the Rex Web site to the public, a comprehensive online teacher tutorial will take the place of an in-person training workshop. The tutorial is included in the Teacher Resources section of the Web site and is found in the Online Resource 1; it provides an overview of the entire program.

High School Students

High school students from four local high schools participated; sixty-four students participated in the preliminary testing, and 164 students participated in the initial rollout. For both activities, the students consisted of predominantly underrepresented minorities. However, only 122 of the 164 students in the initial rollout field test provided

Table 2 Student demographics for the initial rollout

	Demographic	Percent (%) ($N = 122^{a}$)
Gender	Male	31.1
	Female	63.9
	Other	4.9
Race/ethnicity	Black or African American	24.8
	Hispanic or Latino/a	27.4
	European American or White (not Hispanic)	30.8
	Asian or Asian American	6.8
	Multiracial	10.3
	American Indian or Alaska Native	0.0
	Native Hawaiian or other Pacific Islander	0.0
Grade level	Freshman	1.8
	Sophomore	32.9
	Junior	28.7
	Senior	36.6

[a] Only 122 students answered the demographic survey of the 164 students participating in the initial rollout field test

demographic information in an online survey that was administered at the start of the semester (Table 2).

Instructional Program

Preliminary Testing

Initially, we carried out a small preliminary testing exercise in three high school biology classrooms (two teachers, 64 students) to determine any features that would need revision prior to the initial rollout field test of Rex (presented in "Results"). Teachers chose an experiment that supported their current course content and that could be conducted during two consecutive 90-min class periods. One teacher chose the Neuromast Viability experiment, and the other teacher chose to use the 3-Chamber Tank experiment in two classrooms. Rex was designed to foster collaborative work within the classroom—ideally, the program can be used in groups of two to four students. However, 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. To determine how students and teachers actually used the program and to ensure consistent implementation, two 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.

Initial Rollout Field Test

After revising elements of Rex that presented problems in the preliminary testing, the initial rollout was performed with 164 students from eight classrooms (of 5 teachers) consisting of the following courses: Standard Biology, Honors Biology, AP Biology, and Honors Anatomy/Physiology. As with the preliminary testing, teachers chose one experiment that supported their current course content and that could be conducted during two consecutive 90-min class periods (see Table 3).

Data Collection

Classroom Observations

Two author observers attended each class in which Rex was used to ensure that implementation was consistent among the classes and to provide technical help if needed. The observers were well-qualified to assess the implementation in the classroom; all had experience teaching high school biology, and at least one observer of the pair had computer/IT expertise with the Web-based program. The observers played an interactive role; they took notes, discussed technical and process issues with the teachers, and answered student questions. After the experiment was completed, the observers assigned scores ranging from 1 (poor) to 5 (excellent) in the following categories: technology issues, teacher preparedness, teacher engagement, and class management. The complete scoring rubric (with definitions) is found on page 2 in Online Resource 1. The scores for the preliminary testing classes were only used for internal discussion and program modification.

Student Survey

After students completed the Rex experiment and submitted their Notebooks to their teachers, they were provided with a link to a survey through the Rex Web site to assess their situational interest (SI) and to obtain feedback. [The psychological construct of SI aligned well with the design of Rex and our assessments of it immediately after completing a Rex

Table 3 Experiment implementation details

Teacher ID	Course	Level	Experiment
1	Biology	Honors	Startle Response
1	Anatomy/physiology	Honors	Startle Response
1	Biology	Standard	Startle Response
2	Biology	Honors	Startle Response
2	Biology	AP	Startle Response
3	Biology	Honors/Standard	Startle Response
4	Anatomy/physiology	Honors	Novel Tank
5	Biology	AP	Novel Tank

module.] Students were given the option of opting out of the survey. 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. Survey responses received more than six days after the Rex experiment were not included in the analyses. We received 111 surveys of the 164 students in the initial rollout; however, 12 surveys were excluded from analyses because students (1) declined to participate, (2) did not finish the survey, (3) completed the survey more than six days after using Rex, or (4) responded in a manner that suggested they were not reading the questions. Thus, the final sample for the surveys was 99 participants. The SI survey did not include the demographic survey information. The student survey can be found on page 3 in the Online Resource 1.

Determination of Situational Interest The questions assessing SI were developed and validated by Linnenbrink-Garcia et al. (2010) and have subsequently been used in numerous studies. Following the approach used by Linnenbrink-Garcia et al. (2013), we combined the sub-scales of (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) to create a 12-item composite indicator of SI ($\alpha = .96$). Thus, the composite measure indicates students' overall SI, taking into account both their emotional reactions to the instruction and content and their views of the value and importance of the Rex content.

Student Feedback Following the SI questions, the students were asked two open-ended questions as to what they liked most and least about using Rex.

Teacher Feedback

At the completion of each Rex lab, we administered a feedback survey to teachers (found on page 4 in Online Resource 1). The teachers provided ratings on a scale of 1 (poor) to 5 (excellent) of students' overall ability to engage in Rex content. In addition, they indicated how they felt about implementing Rex in their classroom (1 = not very prepared; 5 = very prepared) and their confidence in executing Rex without the help of the authors' presence (1 = could not have done it on my own; 5 = definitely could have done it on my own). The teachers also provided open-ended comments about problems they may encounter or reflections on the implementation.

Data Analysis

Classroom Observations

After a class completed a Rex experiment, the four category scores generated by the observer were averaged to give an overall class score. The overall class scores were averaged between the two observers. For the preliminary testing, there was no analysis of the scores; they were used for internal discussion. For the initial rollout field test, descriptive statistics were calculated; mean scores and standard deviations are presented in the "Results." The inter-rater reliability was very high, with an intra-class correlation (ICC) of 0.992 [0.958, 0.999]. The notes that were taken by the observers were used for contextual information, and they were not subjected to quantitative analysis.

Student Survey

A series of analysis of variances (ANOVAs) were conducted using SPSS to determine whether there were statistically significant differences in students' SI based on class level (honors, standard, or AP), class section, teacher, and Rex experiment.

To analyze the student feedback open responses, we constructed a thematic analysis of the qualitative data. Student answers were assigned a primary coding category consisting of (1) difficulty level, (2) interestingness/authenticity/informativeness, (3) scientific/mathematical content, (4) Rex design/platform, and (5) technical issues. Responses in the content and design categories (3 and 4) were assigned a secondary code to develop a more granular idea of which specific components of the math and science content and Rex design/platform most and least appealed to students. For math and science content-related responses, these secondary codes included (1) the experimental process, (2) study organism, and (3) statistical analysis. For Rex design/platform-related responses, secondary codes included (1) interactivity, (2) Web site features, (3) the Notebook, (4) video clips, and (5) instructions. A tally was made of the number of responses that fell into each primary and secondary coding category to highlight students' favorite and least favorite parts of the Rex experiment. A response that fit more than one category was counted in the tally for both categories. The tallies will inform future modifications to the program.

Teacher Feedback

The scores from each of the three items (student ability, teacher preparedness, teacher confidence) were averaged. Descriptive statistics were calculated; mean scores and standard deviations are presented in the "Results." Teacher comments were not analyzed due to the small number of written comments.

Results

Preliminary Testing

Two teachers conducted the preliminary testing in three biology classrooms (consisting of 64 sophomores and juniors). One teacher chose to conduct the 3-Chamber Tank in two different classes, and the other teacher chose to do the Neuromast Viability experiment. Both experiments were completed within the two 90-min class periods. Although two author-observers attended each of the three classes, the classroom scores were only used internally to guide the authors for problem-shooting and revisions for the initial rollout field test. The author-observers also provided technical help to the students, especially when internet access was lost, or videos did not play.

Based on the authors' observations and notes, the major feature of the experiments that presented a problem was the number of data points to collect. For example, in the Neuromast Viability experiment, there were four groups of fish, five fish per group, and eight neuromast images (taken from the microscope) to score—that equals 160 images to examine. Students complained out-loud that it was too much work, and we agreed. Thus, for the subsequent rollout field test, we pre-filled one third to one half of the data points into the Google spreadsheets so that students could still get the experience of collecting their own data without becoming overwhelmed.

Another feature that presented a problem was calculation of the solution dilutions. Despite the guidance presented in the videos by the scientists, some students seemed to be lost in getting started. Therefore, we made a practice dilution calculation worksheet sheet for teachers to provide to their students in the future rollout field test. We also provided the same worksheet with the answers filled in so students could check their calculations. Both documents were added to the Teacher Resources section of their Rex dashboard.

From the technical standpoint, although we whitelisted the online video YouTube URLs with the school's IT personnel, we found that the videos would not play unless the students first logged into their YouTube account. We provided these instructions to all teachers participating in the rollout field-test.

Initial Rollout Field Test

After the preliminary testing, we carried out the initial rollout field-test in five teachers' biology classes. Of the seven possible Rex experiments, the teachers chose to use two: the Novel Tank test (to assess stress and anxiety after caffeine) and the Startle Response (to test the effect of alcohol on developing larvae reflexes) (Table 3). All of the data reported below were derived from the initial rollout field test, not the preliminary testing.

Classroom Observations As in the preliminary testing, two members of the research team attended each class that was implementing Rex to observe and provide technical help. Despite fixing some of the technology issues in the preliminary testing visits, technology continued to cause some "hiccups" in the rollout field test. Most of the technology issues encountered were related to internet connectivity, including state-wide internet outages and slow Internet connections. However, once connected, Rex performed smoothly on the student Chromebooks and Macs, and any intermittent issues were usually resolved by refreshing the browser or rebooting.

In all three levels of classes (Standard, Honors, and AP), some groups of students worked quickly and independently through the experiment while other groups moved at a slower pace and required help from their teacher. As expected, students in the AP courses worked most quickly without assistance compared to students in the Standard and Honors classes. The solution dilution calculations provided difficulty for some students, especially if their teacher did not use the practice dilution worksheets that we distributed prior to implementation (some teachers did use the practice worksheets the day before in preparation for the experiment). Finally, we observed students with English as a second language turn on the subtitles on YouTube while watching the videos. We reminded the teachers that there is a narrative script of all videos in their Teacher Resources section on the Web site.

Each class was rated by the observers on a five-point scale for technology issues, teacher preparedness, teacher engagement, and classroom management. The average of these four ratings generated an overall class score. The scores, averaged of the two observers' scores, ranged from a high of 5.0 to a low of 2.3 (Table 4). One teacher who had two different classes (AP and Honors Biology) received a score of 5.0 for each class. This teacher had fully prepared prior to implementing the Rex experiment in class; the teacher even ran through the entire experiment ahead of time, and printed out helpful review sheets for the student groups. The teacher's class (AP Biology) that scored a 2.3 experienced several school-wide Internet connection and speed problems that were beyond our control. The Internet slowness made data collection difficult because the novel tank experiment (performed in this class) generated data as videos, not still images. Second, the teacher was minimally prepared for the experiment and made no attempt to engage with the students during its implementation. The majority of the teachers received scores between 3.8 and 5, reflecting moderate preparedness and a few technology glitches.

Table 4 Observers' class scores

Teacher ID	Class	Technology	Teacher preparedness	Teacher engagement	Classroom management	Overall class score
		Average scores (1 = lowest; 5 = highest)				(Average)
1	Biology (Standard)	2.8	3.8	5	3.5	3.8
1	Biology (Honors)	2.8	3.8	5	4	3.9
1	Anat/Phys (Honors)	2.8	3.8	5	3.5	3.8
2	Biology (Honors)	4.8	5	5	5	5
2	Biology (AP)	5	5	5	5	5
3	Biology (Hon/Std)	5	5	5	5	5
4	Anat/Phys (Honors)	4	3.5	5	5	4.5
5	Biology (AP)	3	2	1	3	2.3
	Mean	3.8	4.0	4.5	4.3	4.2
	SD	1.04	1.03	1.41	0.85	0.93

Most teachers were able to finish Rex within two 90-min class periods. Two teachers wrapped up in a short session on a third day due to internet instability.

Student Surveys—Assessment of Situational Interest Overall, students reported a moderate level of SI as a function of participating in the Rex experiments during the initial rollout ($M = 3.40$, $SD = 0.79$). More specifically, 72 students responded above neutral (i.e., had average scale values greater than 3.0 on a 5-point scale). Twenty-one students reported that they agreed or strongly agreed (i.e., had average scale values of 4.0 or greater on a 5-point scale) that 1) the content taught as part of the Rex experiments was meaningful to them and exciting and 2) doing the Rex experiments was exciting and engaging (Fig. 8).

To consider whether students had similar levels of SI after participating in Rex across classes, we conducted a series of ANOVAs to compare student SI based on class level, class section, teacher, and experiment. For class level and Rex experiment, $N = 99$, whereas $N = 98$ for class section and teacher because Teacher 4, Class 1 had only one student with a valid survey response. That student was therefore excluded from class and teacher analyses.

There were no significant differences in SI across any of these variables. Specifically, there were no statistically significant differences in students' SI as a function of class level: standard ($M = 3.339$, $SD = 0.762$), honors ($M = 3.360$, $SD = 0.862$), AP ($M = 3.514$, $SD = 0.659$), $F(3, 95) = 0.416$, $p = 0.668$. In addition, there were no statistically significant differences in SI between class sections, $F(7, 90) = 0.491$, $p = 0.814$ (see Table 5 for means), or based on teacher, $F(4, 93) = 0.540$, $p = 0.656$, (see Table 6 for means). Finally, SI did not significantly vary between the Startle Response experiment ($M = 3.379$, $SD = 0.826$) and the Novel Tank experiment ($M = 3.477$, $SD = 0.662$), $F(2, 96) = 0.485$, $p = 0.488$. The lack of variability in SI across different levels of classes or based on different sections, teachers, or type of experiments suggests that Rex is fairly stable across various implementations.

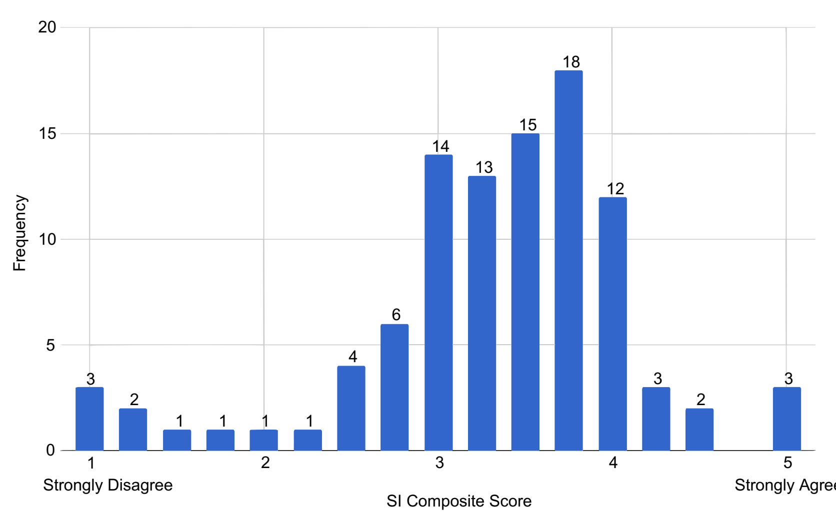

Fig. 8 Distribution of situational interest (SI) in Rex across classrooms SI scores on the X-axis ranged on a Likert Scale from 1 (strongly disagree) to 5 (strongly agree). The number of students associated with each score is written above the blue bar. $N = 99$

Table 5 Mean situational interest scores by class section

Class section	Number[a]	Mean	SD
2	23	3.388	0.867
3	7	3.655	0.626
4	8	3.073	0.963
5	21	3.468	0.677
6	17	3.324	0.759
7	13	3.545	0.856
8	9	3.280	0.910

[a] $N = 98$ for class section because Teacher 4, Class 1 had only one student with a valid survey response. That student was therefore excluded from class analysis

Student Surveys—Feedback About Rex We conducted a thematic analysis of the open-ended responses from the student surveys in the initial rollout field-test. When queried about what students liked most about Rex, the most common positive comments about Rex content focused on design components of the platform as their favorite part of the experience (Table 7). Of the 99 respondents, 42 cited some element of the Rex learning environment as their favorite part of Rex, e.g., "I liked that we had a guide to go a long [sic] with the experiment" and "easy to follow with the help of the videos." Students reported that they enjoyed being able to collect actual data, learning to use spreadsheets, the "clear," "easy to follow" instructions and videos, and the interactivity of the platform. A further 40 cited some element of the content or experimental process as their favorite part of Rex, including comments relating to the study organisms, e.g., "the fish responding to the tap on the glass," or use of statistics or Google Spreadsheets, e.g., "being able to learn how to do certain things with Excel" in the experiment. Eighteen respondents cited how interesting, informative, or authentic the experiments were as the best part of Rex, and 13 noted that they appreciated the additional scaffolding provided within Rex.

Interestingly, students' chief dislike about the Rex experience also related primarily to their engagement with specific parts of the material and the use of data collection and spreadsheets (Table 8), indicating that student opinion varied widely on various elements of the program. Specifically, of the 99 students responding to the qualitative responses, 35 noted issues relating to the design or platform of the experiment. Comments frequently included mention of the duration of activities, e.g., "It was very tedious work and it took a while," the videos, e.g., "took too long to watch all the videos," the lack of interactivity with real organisms, e.g., "We didn't see the fish in person," or the use of spreadsheets, e.g., "having to fill out all the data"). Twenty-eight of the students cited some element of the content, most frequently the mathematical component involved in the statistical analyses and graphing, e.g., "have to answer and calculate all these answers and doing the math" or "the math" or "making the graph," as their least favorite part of Rex.

Table 6 Mean situational interest scores by teacher

Teacher	Number[a]	Mean	SD
1	39	3.387	0.813
2	30	3.450	0.815
3	8	3.073	0.963
5	21	3.468	0.677

[a] $N = 98$ for teacher because Teacher 4, Class 1 had only one student with a valid survey response. That student was therefore excluded from the teacher analysis

Teacher Surveys Overall, feedback from the teachers using Rex in their classrooms was positive. Based on their comments, 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' ability to engage with the academic content of Rex on a scale of 1 (poor) to 5 (excellent). Across the eight classes using Rex, teachers rated students' ability to engage with the content of Rex as good ($M = 3.5$, $SD = 0.76$). Thus, Rex biological content was fairly challenging but manageable for most students. However, there was a wide variation in how teachers felt about being prepared to implement Rex in their classes. While two of the teachers reported that they felt very prepared, one teacher reported feeling poorly prepared ($M = 3.0$, $SD = 1.73$). Two teachers did not respond to this question.

Teachers also reported how confident they felt to implement Rex without the onsite support from the authors ($M = 3.3$, $SD = 0.76$). One teacher who used Rex in an Honors Biology class first had a confidence score of 3, but indicated that for the second class, AP Biology, the confidence increased to a level 5. Another teacher who did not feel confident implementing Rex in the classroom without help from the authors was the same teacher who felt unprepared. Finally, teachers were asked to comment about the support by the authors in their classes: "The little insights for website use and how to do things smoother were greatly appreciated.", 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. Qualitatively, positive student comments aligned with several of our goals in designing

Table 7 Students' favorite part of Rex ($N = 99$)

Primary coding category (themes)	Secondary coding category (sub-themes)	Number	Responses (exactly as written)
Difficulty level		13	•"They were easy to follow with the help of videos guiding me step by step." •"Every misunderstanding possible was adequately anticipated"
Interestingness, authenticity, or informative nature		18	•"Fun"/"Entertaining"/"Cool" •"I enjoyed how down to earth the production was. I did not feel overly babied." •"I liked the information… that I can relate to my life"
Scientific or mathematical content ($n = 40$)	Experimental process	7	•"Collecting data" •"It was interesting to see the empirical evidence…"
	Study organism	27	•"I liked that it had to do with zebra fish because fish are cool" •"The fish responding to the tap on the glass"
	Statistical analysis and graphing	8	•"When we got to work on the graphs" •"The calculations"
Rex design and/or platform ($n = 42$)	Use of spreadsheets	3	•"Learning how to use the spreadsheet" •"Putting it [data] on excel"
	Interactivity	5	•"We got to play a large roll [sic] in the experiment" •"The videos helped give us interaction with real[ly] scientists"
	Web site features	4	•"I liked that we got to do real expirements [sic] in a vertial [sic] setting" •"The fact that it's on a computer"
	Notebook	3	•"I like how easy it was to record our observations and answers within our notebook"
	Video clips	21	•"The videos were pretty interesting •"I enjoyed having the videos and seeing real life what we would do…"
	Instructions	7	•"I like that we had a guide to go a long [sic] with the experiment
Uncategorized		5	•"Nothing"
No response		5	

[a] Total responses exceed 99 as both primary and secondary codes could be double-coded

Rex, and negative comments led to some early adjustments in implementation of the experiments. Our 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. Last, most of the teachers who used Rex in their classes were positive about the academic rigor of the program and felt prepared to participate in its implementation.

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 preliminary testing 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, or be available for separate download prior to class.

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 Web site. 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.

Table 8 Students' least favorite part of Rex ($N = 99$)

Primary coding category (themes)	Secondary coding category (sub-themes)	Number	Responses (exactly as written)
Difficulty level		11	•"Kind of unclear when we did the ANOVA"
			•"The questions were a bit difficult to understand"
Interestingness, authenticity, or informative nature		11	•"Need like some games or something"
			•"It's not entertaining…"
Scientific or mathematical content	Experimental process	7	•"Having to record the movement"
			•"There was so much to doing one experimeny [sic]"
($n = 28$)	Study organism	4	•"There [sic] reaction"
			•"The fish died"
	Statistical analysis and graphing	17	•"I personally do not like math and doing that sucked"
			•"Graphing"
Rex design and/or platform	Use of spreadsheets	6	•"All the Excel use"
($n = 35$)	Interactivity	7	•"We did not do any hands on things"
	Web site features	5	•"I did not like the back and forth"
			•"White board portion [should] be made digitally"
	Video clips	12	•"It took too long to watch all the videos"
			•"Cheesy videos"
	Duration/ repetition	9	•"We had to answer questions that were very similar to other questions"
			•"It took a long time"
			•"Tedious work"
Technical difficulties[b]		4	•"The videos not loading"
Uncategorized		9	•"Undetermined"
			•"Everything"
No response/ positive response[c]		10	

[a] Total responses exceed 99 as both primary and secondary codes could be double-coded

[b] An additional category for technical difficulties was added for the second set of responses because some classes had complaints about videos not loading that were unrelated to the platform itself but more reflective of bandwidth/local technology issues

[c] A few responses to this "dislike" question were actually positive responses about Rex and were thus coded in the "no response" category

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 technical issues and teacher preparation during implementation were important aspects of a successful Rex experience. As observers, we noted that Rex tended to run smoothly when connectivity to the internet was stable and fast—in the classroom that had unstable internet access, students became impatient and annoyed, and it appeared to the observers that the students became less engaged in the experiment. In addition, a positive experience with Rex occurred 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 to complete the experiments in the recommended two 90-min class periods. Teachers who have lower performing students in their classrooms might benefit from providing additional preparation for the Rex unit to their students before implementing Rex in class. For example, students could practice carrying out simple dilution calculations. Additionally, teachers could 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 opportunity to engage with a study organism not generally used in high school science classes: many of the positive comments cited students' excitement about the zebrafish and their ability to make choices about experimental design. Many explicitly mentioned the authenticity or relevance of the biology 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 authentic (albeit virtual) scientific investigation. Student comments reflected enjoyment at being engaged with the experimental process and getting to collect real data, suggesting that this approach is a good "hook" for learning the practice of science.

Some features of the Rex experiments received both positive and negative feedback, indicating that individual student preferences and/or readiness may play a role in how particular aspects of Rex are perceived. One of the most common responses from students about their least favorite part of Rex was collection and analysis of large amounts of data. The comments about the tedious nature of collecting data provide further support for our decision after the preliminary testing to pre-fill some of the data into data tables and to reduce the data collection workload for students participating in the experiment. However, it is clear that even with the reduction in the amount of data students needed to enter, some students still found this aspect of Rex tedious. In terms of the data analysis, some students had never worked with spreadsheets nor created graphs on a computer. Yet, some students commented on enjoying learning and using these skills, while others reported frustration at the more mathematical aspects of the data analysis. Although learning such technical and mathematical skills was not a primary goal of Rex, it is an added benefit that may also help improve students' understanding of basic statistics and computer literacy. Nonetheless, given that many students struggled with this aspect, it may be that additional scaffolding in the use and learning of statistics would make Rex more accessible and enjoyable for more students.

Student Situational Interest

Students demonstrated a moderate level of SI across all classes, and the extent of SI was similar regardless of class level (e.g., standard, honors, AP, anatomy/physiology), teacher, class section, and experiment. The similar SI scores observed in biology classes of different levels is surprising given our observations that some students in standard level courses struggled with some of the Rex material. Additional preparation for lower performing students, or those with reading difficulties or lower prior mathematical knowledge prior to the implementation of Rex in class, could help these students complete a Rex experiment more easily and help promote SI. Nonetheless, our results suggest 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. However, a limitation of this small field-test is that only two of the seven Rex experiments were chosen by the teachers, so future exploration of SI after completing other Rex experiments with more teachers would be informative. 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.

Conclusion

Virtual Rex Experiments and the Classroom

Nontraditional laboratories, and specifically virtual laboratory experiments, have been shown to be equally effective with traditional physical laboratories when measuring student learning outcomes (Brinson 2015; de Jong et al. 2013; Rutten et al. 2012). Although specific learning outcomes were not measured in this study, the Rex platform incorporates elements that have been shown to be effective with regard 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 (de Jong et al. 2013; Schneider and Preckel 2017; Yaron et al. 2010). Our program uses a more holistic approach to inquiry by involving students in an authentic scientific investigation that encourages them to incorporate background information, consider multiple alternative explanations for their results, and think about potential sources of error and possible future experiments. The act of collecting data from real experiments by the students themselves should help them to think deeply about and interpret their results, identify sources of error, and design additional experiments.

In sum, our initial design and development work that we describe here suggests that Rex can be implemented in a variety of biology classes and that students generally respond similarly well to various Rex experiments. Although only two experiments were used in this small study, it appears that teachers can enact whatever Rex experiments best fit their unit of study. Our findings also highlight some of the challenges with developing and implementing a virtual experiment platform such as a Rex. For next steps, we aim to provide teacher training for using Rex at workshops, and to investigate the impact of a fuller integration of Rex into the classroom (e.g., multiple experiments) on student learning and self-efficacy. Additional studies may address the home-schooled and online classroom populations, whose access to laboratory experiments is limited. Finally, we encourage researchers to use this open resource to test outcomes that align with their own interests. We hope the lessons presented here will be useful to other researchers interested in taking on the challenging task of providing alternative methods for providing high-quality and authentic biology laboratory experiments in the high school classroom.

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Compliance with Ethical Standards

Research Involving Human Participants and/or Animals

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. IRB approval for exempt research with human subjects was obtained from the Duke University Medical Center Institutional Review Board (#Pro00043061) prior to beginning the project. All applicable international, national, and/or institutional guidelines for the care and use of animals were followed. All procedures performed in studies involving animals were in accordance with the ethical standards of the institution or practice at which the studies were conducted.

Conflict of Interest The authors declare that they have no conflict of interest.

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